JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HIGHWAY ENGINEERING STREAM

COMPARATIVE STUDY ON SUITABILITY OF CRUMB RUBBER AND WASTE MARBLE DUST AS FILLER MATERIAL ON HOT MIX ASPHALT PAVEMENT

A Final Thesis submitted to the School of Graduate studies of Jimma University. In partial fulfillment of the requirements for the Degree of Masters of Science in Highway Engineering.

By:

Haile Zenebe Dulecha

February 2022

Jimma, Ethiopia

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DECLARATION

I declare that this research entitled "Comparative study on suitability of Crumb Rubber and waste Marble Dust as filler material on hot mix asphalt pavement" is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.

Dulecha Zenebe Haile	______________	______________
name	signature	date

As research Adviser, I hereby certify that I have read and evaluated this thesis paper prepared under my guidance, by First Father Grand, Father, Name listed above and entitled "COMPARATIVE STUDY ON SUITABILITY OF CRUMB RUBBER AND WASTE MARBLE DUST AS FILLER MATERIAL ON HOT MIX ASPHALT" would be accepted as a fulfilling requirement for the Degree Master of Science in Highway Engineering.

Professor Emer. T. Quezon	……………………….	__________
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Eng Anuar Nigusie, MSc	…………………………	__________
Co-Advisor	Signature	Date

ACKNOWLEGNMENTS

I would like to express my sincere gratitude from the bottom of my heart to my Advisor Professor Emer. T. Quezon for his genuine and valuable assist, professional guidance, valuable advice and endless encouragement. Next, I express my thanks to my Co-Advisor Anuar Nigusie, (MSc.) for their invaluable guidance throughout the thesis work and their voluntariness to support.

Finally, I would like to forward my honorable appreciation and thanks to my family for their support during my study and also to my colleagues who contribute a lot forwarding their positive advice and support. My friend Mesay Tafese, thank you so much for your great support. Finally, my profound and appreciation goes to Oromia Road Authority (ORA) and Jimma University Institute of Technology for providing and giving me the opportunity of the scholarship program in pursuing my master’s degree in Highway Engineering.

ABSTRACT

Globally, waste materials from construction and industry have been increasingly utilized as alternative raw materials in asphalt mixtures. One of this wastage materials are waste marble dust (WMD) and crumb rubber (CR) during utilized and processing of cutting, shaping, polishing and tires destroyed are huge amount of wastages produced. In line with this one of the main problems in the construction of asphalt paving mixture is quality of material used, insufficient amount of qualified filler. To overcome this problem, it is important to come across alternative filler material that can address this gap which is easily available. Thus, this study was expanding the mindfulness about the present issues of materials waste reuse and utilization in order to reduce the environmental pollution, decrease construction costs, conserve natural resources. Hence, the main objective of this study is to investigate the potential suitability of WMD and CR to replace CSD.

In this study to prepare HMA mixture materials like different size of aggregate, 60/70 bitumen, CSD, WMD and CR are used and laboratory test like material quality test, engineering properties of HMA and moisture susceptibility was done to achieve the objective. Based on this totally one hundred twenty (120) specimens are prepared. Hence three different serial asphalt concrete samples are produced using CSD in different dosages 4.5, 5.5, and 6.5% as mineral filler with five different bitumen content (4.3, 4.8, 5.3, 5.8 and 6.3%) and three samples for each. bitumen content was selected by using MS-2 design method with curve plotting and common range selecting this were conducted for the best fit selected 4.85% optimum bitumen content at its corresponding 5.5% filler content. The Marshall Properties of control mix design at optimum filler content was 11.55 kN, 3.21 mm, 2.343 g/cm^3, 4.2%, 14% and 72.5% for stability, flow, bulk specific gravity, air void, VMA and VFA respectively.

Partial replacement of CSD was done with WMD and CR at replacement of 0, 20, 40, 60, 80 and 100 % and 0, 5, 10, 15, 20 and 25% by the mass of CSD respectively. The optimum potential replacement of CR and WMD result finding shows 15% and 100% respectively as filler in HMA. The result of tensile strength ratio (TSR) at optimum of 100% CSD, 100% WMD and 15% CR results are 85.61, 86.49 and 84.12%, respectively. Therefore, WMD are better resistance to moisture effects, Followed the mixes prepared CR is lowest moisture resistance as compared with CSD fillers

Keywords: *Crumb rubber, Crushed stone dust, Hot Mix Asphalt, Marshal Stability, Tensile strength ratio and Waste marble dust*

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ACRONYMS

AASHTO	American Associates of State Highway and Transport Officials
ASTM	American Society for Testing and Materials
AC	Asphalt Concrete
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
CR	Crumb Rubber
CSD	Crush Stone Dust
ERA	Ethiopia Road Authority
HMA	Hot Mix Asphalt
ITS	Indirect Tensile Strength
LLA	Los Angeles Abrasion Value
MD	Moisture damage
MTD	Maximum Theoretical Density
NAPA	National Asphalt Pavement Association
NP	Non Plastic
OBC	Optimum Bitumen Content
OFC	Optimum Filler Content
OPC	Ordinary Portland cement
PRD	Proportional Rut Depth
TSR	Tensile Strength Ratio
WMD	Waste Marble Dust
VFA	Voids Filled Asphalt
VMA	Void Mineral Aggregate
VMT	Void Mix Total

CHAPTER ONE

INTRODUCTION

1.1. Background of study

Globally, concern to waste materials in construction industry is going on rapidly now days to day. This is being done due to the waste materials would cost environmental hazard if these are not properly utilized and kept open in the environment, the waste materials may enhance the strength and durability characteristics of the original materials into which these are utilized and the materials could reduce the cost of construction incase these materials replace the conventional materials. Waste is any material that is a by-product of human and industrial activities such types of waste material is marble dust, crumb rubber, Rice Husk Ash (Junaid Ahmed, 2016),(Yarhim, 2006)

Nowadays in Ethiopia, has allocated a huge amount of waste material rising from industrial and agricultural residue, create acute environmental problems both in terms of their treatment and disposal. The construction industry has been identified as one of the areas where the waste can be absorbed, with the majority of such materials used as filler in concrete(Maganari, 2005) (Anteneh, 2014).

Therefor majority of developed country and Ethiopia roads are used flexible pavements, which are less expensive than rigid pavements but still costly for a developing country. Increases in road construction costs have been common in Ethiopia, and many projects have been delayed or rejected due to budget constraints. Asphalt binder is well-known for its major contribution to flexible pavement construction costs (Tadesse, 2017)

Asphalt mixture is a combination of binder, aggregate, and air in different relative proportions that determine the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement. In highway construction technology, efforts are being made in the area of utilizing waste materials instead of discarding or incinerating them. Such wastes include industrial, Agricultural and Municipal solid waste(Murana and Sani, 2015)

In addition, fillers affect the workability, moisture sensitivity, stiffness, and ageing characteristics of hot mix asphalt (Ratnasamy, 2013). In order to improve the pavement performance and durability, it is necessary to prepare a good mix which is highly influenced by the components of the filler. In this regard understanding the effect of fillers on the Asphalt concrete mix is essential.

Among the mining sectors, the marble processing plant is one of the important industrial sectors in our country. There are more than fourteen marble processing plants in Ethiopia located in different towns. In Ethiopia 770,000.00 to 1,000,000.00 m^2 of marble commodities were produced in a year (Thomas Yager, 2016).

Marble waste is one type of industrial byproduct of materials that can be reused. It is the waste created during the cutting, shaping, and polishing of the marble processing plants. From previous studies conducted in advanced countries, the possibility of using marble waste dust as filler substitute in hot asphalt mixtures is confirmed, and promising results showed with improved properties (Eisa and Basiouny, 2018). However, the actual use of marble waste (MWD) filler has not been known as an alternative filler in local road construction, and the effects of MWD filler.

As the amount of car is increasing quickly, tire waste becomes a significant environmental fear. Crumb rubber is a material generated when used tires are destroyed and commuted. In the world's disposal of waste tires have three main methods to cope with such things as landfills, burning & recycling. Scrap tire (recycled tire rubber) applied to pavement can be the best way to reduce large quantities of waste tires while at the same time improving the engineering properties of asphalt mixtures.

These studies try to find adequate combination of the need of safe and economic disposal of waste materials and the need of better and more cost-effective construction materials. Using recycled materials in road pavements is nowadays considered not only as a positive option in terms of sustainability, but also, as an attractive option in means of providing enhanced performance in service (Justo and Veeraragavan, 2002).

Disposal of that large quantity of wastes especially non decaying waste materials become a problematic of great concern in developed as well as in developing countries. (Justo and Veeraragavan, 2002).

1.2. Statement of Problem

Globally, large amount of waste product material like WMD and CR on construction and industry are rising day to day (Yongjie and S 2004). Due to this there are different fillers which are used in HMA to improve the mechanical properties of HMA and to reduce conserving natural resources, disposing of waste materials (which are often unsightly) and freeing up valuable land for other uses (Blewett and Woodward 2000) A large amount of waste is produced as a result of rapid economic growth and continued increased consumption (Zainudin, 2016). Majority of developed country and Ethiopia roads pavements are still cost hence many projects have been delayed or rejected due to budget constraints. Asphalt binder is well-known for its major contribution to construction costs (Tadesse, 2017).

On the other hand, one of the main problems in the construction of highway pavement is insufficiency of amount of mineral fillers from crushing of rocks (Zemichael, 2007). Specifically, in my study area also there is a problem of asphalt filler constraints. Depending on this it was necessary to find an alternative to replace CSD with waste material available in our local like WMD and CR. Utilizing these waste materials as alternative raw materials in asphalt pavement can be promising method to reduce environmental pollution, decrease consumption of natural recourses and may be to reduce construction costs. Moreover, making use of combined fillers (WMD and CR) minimizes the environmental deterioration caused by blasting of quarries during the production of rock dust and disposal of wastes (WMD and CR) on land. This waste material as an alternative replacement for CSD on HMA and a possible solution and to recommend the Marshall property results of these fillers when we use as alternative fillers in the future. It is expected that this thesis results are serve as a base to use combined fillers for effective HMA mix design and minimize possible delays and associated cost caused by filler shortage in asphalt mixture road project.

Therefore, the aim was focused on the use of locally available waste materials at evaluating suitability of WMD and CR significant saving by partial replacement amount as mineral filler in HMA asphalt production

1.3 Research Questions

Specifically, this study aimed to answer the following questions:

- What are the physical properties of HMA material and chemical properties of CR and WMD?
- What are the potential suitability of WMD and CR powder as filler material on marshal properties of hot mix asphalt?
- Can the replacement of CR and WMD at optimum replacement of filler on mix design of the study fulfill moisture sensitivity?

1.4. General Objectives

The general objective of this research is to evaluate the suitability of Waste Marble Dust and Crumb Rubber powder as a filler material in hot mix asphalt concrete.

1.4.1. Specific Objectives

- To identify physical properties of HMA material and chemical properties of WMD and CR.
- To compere the potential suitability of WMD and CR as replacement of CSD using relevant parameters and properties of asphalt concrete.
- To determine moisture susceptibility at boundary of optimum filler content of material used in replacement of; CSD, WMD and CR on HMA.

1.5. Scope and limitation of the Study

These researches are performed focused on suitability of filler type and determination of their optimum content in HMA mix design. The two filler type that was investigated in this study is WMD and CR as a substitute for the CSD in paving of HMA. This HMA characteristic of Marshall Properties such as voids in mineral aggregate VMA, Air void VA, VFA, Marshall Stability, flow of asphalt bituminous mixture produced and water susceptibility of the mixes design. 60/70 penetration grade of bitumen, which is the most common type of asphalt penetration grade we are using in our country especially in mild climate, was used to evaluate hot mix asphalt concrete properties and the substitute of CSD with the former two selected fillers at the nominal size of mineral aggregate gradation was carried on.

Lastly, asphalt performance test was performed in order to evaluate the moisture resistivity of the mix design as per AASHTO T283/ASTM D4867. In this test, indirect tensile strength tests for both dry and wet conditions were undertaken and followed by determination of TSR value of the mixes.

1.6. Significance of the Study

CSD is the main material that is used as a filler material in HMA production. This research is focused on replacing of CSD filler partially and fully by CR and WMD. Currently the amount CSD that gets from crushing of aggregates is insufficient. Due to the intention of this insufficient amount, this research is focused on replacing of crushed stone dust fillers partially or fully by WMD and CR by determining all the necessary engineering properties. Hence the findings of this research work are help to; minimize the problem of insufficient amount of crushed stone dust fillers by replacing local available waste material, to reduce environmental pollution, decrease consumption of natural recourses, ecofriendly, biodegradable and available of huge quantities of industrial waste and preparing these locally available materials as income source for the owners. To make these waste materials well effective and ready for replacing CSD fillers in HMA.

Generally, this research was given a clue to those who are interested in conducting research on evaluation of partially or fully replacing asphalt filler by WMD and CR.

CHAPTER TWO
LITRATURE REVIEW

2.1. Introduction

Asphalt concrete is a mixture of aggregate, filler and asphalt binder. These materials are mixed in an asphalt plant and then hot lay to form the surface course of flexible pavement. The properties of asphalt concrete depend on; the quality of its components (aggregates, fillers asphalt binder and aggregates), mix proportions and construction process (Asphalt Institute 1994). All materials of asphalt concrete cemented by the asphalt binder and blended at pre-specified weight proportions determined from the mix design method. The blend of mineral filler and asphalt binder forms the asphalt mastic destined. And it plays a major role in controlling the mechanical behavior of its mixture. (Roman 2017).

Hot mix asphalt concrete is the most popular material utilized for wearing course surface pavement in the world. It basically combined of coarse aggregates, fine aggregates, mineral fillers and asphalt binder. When aggregate bound by bitumen, it acts as a strong stone framework that gives strength to the mixture. The characteristics of HMA mainly depends on the individual properties of its ingredients and how they counter with each other in the mixture. (AASHTO, 1995).

HMA, as the name suggests, is mixed, placed, and compacted at a higher temperature. Hot mix asphalt mix design is the process of determining an appropriate proportion of the materials that would give long lasting performance paving mixture during its service life. It is a mixture of binder, aggregate, and air in different relative proportions that determine the physical properties of the asphalt concrete mix and, ultimately, how the mix will perform as a finished pavement. (Zemichael, 2007).

Hot mix asphalt concrete produced by heating the asphalt binder to decrease its viscosity and drying the aggregate prior to removing moisture from it prior to mixing. Mixing in the asphalt plant is generally performed with the aggregate at about 150ºC for virgin asphalt and 166 ºC for polymer modified asphalt, and the asphalt cement at 150ºC. Laying and compaction must be performed while the asphalt is sufficiently hot. Thus, the design of asphalt paving mixes is largely a matter of selecting and proportioning the ingredient materials to optimize all desired properties in the finished paved road. (Zemichael, 2007).

2.1.1 Aggregate

The main aggregates used in road pavements on their own or in combination with a cementations material are either natural rock materials, gravels and sands, or slag aggregates (Brennan and Flaherty, 2002). Aggregate is a collective term for sand, gravel and crushed stone mineral material in their natural or processed state. Fine aggregate defined by (AASHTO M-147) (Singh and Sakale, 2018). as natural or crushed sand passing the number10 sieve and mineral particles passing the number 200 sieve. Coarse aggregate defined also by (AASHTO M-147) as hard, durable particles or fragments of stone, gravel or slag retained on the number10 sieve. Usually coarse aggregate has a toughness and abrasion resistance requirement. (AASHTO, 1995).

The aggregate should have characterization of ; Be angular and not excessively flaky, to provide good mechanical interlock, Be clean and free of clay and organic material, Be resistant to abrasion and polishing when exposed to traffic, Be strong enough to resist crushing during mixing and laying as well as in service, Be a non-absorptive - highly absorptive aggregate are wasteful of bitumen and also give rise to problems in mix design. (ERA, 2002)

Aggregates take up the major portion of base course and prime materials used. Aggregate for base course shall consist of hard, durable particles or fragments of crushed stone, crushed slag or crushed or natural gravel and filler of natural or crushed sand or other finely divided mineral matter. The material shall be of such nature that it can be compacted readily to form a firm, stable base. The suitability of base course material for use depends primarily on the design traffic level of the pavement and climate. For higher class of traffic base course can be bituminous and material stabilized with cement or lime may also be considered.(DPWH, 2004).

2.1.2 Aggregate gradation

Aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight and total percent passing various sieve sizes. It is determined by sieve analysis, that is, by passing the material through a series of sieves stacked with progressively smaller openings from top to bottom. And weighing the material retained on each sieve. It is the most important property of an aggregate that affects almost all the properties of a HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. (Freddy 1996).

Theoretically, it would seem reasonable that the best gradation for HMA is one that gives the densest particle packing. The gradation having maximum density provides increased stability through increased inter-particle contacts and reduced voids in the mineral aggregate. However, there must be sufficient air void space to permit enough asphalt cement to be incorporated to ensure durability. Meanwhile it is still necessary leaving some air space in the mixture to avoid bleeding and/or rutting. A tightly packed aggregate (low VMA) also results in a mixture that is more sensitive to slight changes in binder content. (Freddy 1996)

2.1.3. Asphalt binder (bitumen)

As one of the pavement construction ingredients, the use of amount bitumen is low when compared to the other ingredients. Bituminous binders form another important component of hot-mix asphalt mixtures. Asphalt binders are viscos-elastic materials whose resistance to deformation under load is very sensitive to loading time and temperature. The empirical measures of binder properties include penetration, ductility, and softening point.

Asphalt is insoluble black or brown amorphous solids that significantly affect the rheology of bitumen. In addition to carbon and hydrogen, some nitrogen, sulfur and oxygen atoms are present. Increasing asphalt produces a harder, more viscous, bitumen with lower penetration and higher softening point and consequently higher viscosity. (Hunter, 2015).

2.1.4 Mineralogical composition and chemical properties of aggregates

The basic physiochemical properties such as wetting, adhesion and stripping are function of composition and structure of minerals in aggregates. The most important minerals found in aggregates are silica, feldspars, ferromagnesian, carbonates and clay minerals. Quartz (silica) and feldspars are harder and more polish resistant minerals while lime stones are soft. One of the most important effects of aggregate mineralogy on the performances of HMA is its influence on adhesion and moisture damage. Asphalt cement bonds better to aggregate with certain mineral types. For instance, Asphalt cement bond to carbonate aggregates (limestone) than to siliceous aggregates (gravel). Mineralogy of an aggregate has greater effect on performances of concrete mixes than for asphalt mixes. But; the project specification requirement should be selected so that aggregates having undesirable mineral components are not accepted for use (Freddy 1996) The chemical properties of aggregate identify the chemical composition that an aggregate undergo due to chemical action. The chemical compositions of aggregates based on chemical analysis are usually given in terms of oxides, regardless of whether such oxides are present in the sample. Despite the surface chemistry of the aggregate particles plays an important role in HMA performances as asphalt cement must wet the aggregate surface, stick to aggregate and resist stripping of the asphalt films in the presence of water, the Chemical properties of aggregates have little effect on their suitability and performance, except as they affect adhesion of asphalt binder to the aggregate. (Freddy 1996).

2.1.5. Fillers

The term mineral filler is typically referred to the fine mineral particle with physical size passing the 200-mesh sieve (smaller than 75 microns). Mineral fillers are by-products of various stone crushing procedures, manifesting the feasibility of including them in the design of hot mix asphalt (HMA) (Eltaher and Ratnasamy, 2016). Mineral fillers increase the stiffness of the asphalt mortar matrix. Mineral fillers also affect workability, moisture resistance, and aging characteristics of HMA mixtures. Generally, filler plays an important role in properties of bituminous mixture particularly in terms of air voids, voids in mineral aggregate. (Kar,b 2012).

Mineral filler has two important roles in hot mix asphalt (HMA). The first being to fill the voids between course and fine aggregates; hence, denser and stiffer layers can be obtained. The second being to provide more contact points between aggregates, Bitumen film cover filler's large surface area and stiffer contact points can be generated with the aggregates. Mostly, crushed stone dust has been utilized in hot mix asphalt as mineral filler. (AASHTO, 1995).

The finer materials than the fine aggregates used in hot mix design to fill the void in the mix are termed as mineral filler. They impart stiffness and toughness to the binder in asphalt hot mix, which save the mix from rutting and fatigue phenomena. Filler also modifies the ageing process of hot mix, and it prevents moisture damages (Grabowski and Wilanowicz, 2008). Moreover, filler plays an important role to improve the cohesion of binding materials. In general, it consists of finely graded rock dust, hydrated lime or cement. (MORTH, 2013)

Asphalt binder (bitumen) which holds aggregates together in HMA is the thick, heavy residue remaining after refining crude oil. Asphalt binder consists mostly of carbon and hydrogen, with little amounts of oxygen, sulfur, and several metals. The physical properties of the asphalt binder vary considerably with temperature. At high temperature, asphalt binder was fluid with a low consistency similar to that of oil. At room temperature, most asphalt binders should have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Many asphalt binders will contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders. Most of asphalt binder specification was designed to control changes in consistency with temperature. (Transportation Research, 2011).

2.1.6. Crushed Aggregate

During production, construction, and the service life of the road, the aggregates are subjected to the effects of weather, climate, and a range of mechanical processes which together contribute to the deterioration in its physical condition. Therefore, when the construction of a road is necessary, it is important to obtain a material sufficiently durable to last the design life of the road so that its performance is not affected by deterioration or degradation of the material. The qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity, and porosity. In addition to these properties, the micro-texture of the aggregate particles also strongly influences the performance of a compacted HMA layer. Smooth surfaced river gravel, even partly crushed, may not generate as much internal friction as a crushed aggregate from particles having a coarse micro-texture. Therefore, aggregates should have the following characteristics for aggregates used in HMA. (NCAT 2011). Aggregates should be:

- Angular and not excessively flaky, to provide good mechanical interlock.
- Clean and free of clay and organic material.
- Resistant to abrasion and polishing when exposed to traffic.
- Strong enough to resist crushing during mixing and lying as well as in service.
- Non-absorptive since highly absorptive aggregate are wasteful of bitumen and also give rise to problems in mix the design.
- Have good affinity with bitumen, hydrophilic aggregates may be acceptable only where protection from water can be guaranteed or a suitable adhesion agent is used.

2.1.7 Crumb Rubber

The world's disposal of waste tires has three main methods to cope with such things as landfills, burning & recycling. Scrap tire (recycled tire rubber) applied to pavement can be the best way to reduce large quantities of waste tires while at the same time improving the engineering properties of asphalt mixtures. Crumb rubber is a word used in automotive and truck scrap tires for recycled rubber. There are two significant technologies for mechanical processing of the ambient crumb rubber and cryogenic processing of the two procedures, the cryogenic method is more costly but it generates smoother and lower crumbs.(Patil Akshay and Anand B, 2020)

The fast growth of the automotive sector and a greater standard of living of individuals in Ethiopia, the number of cars raised significantly, Ethiopia facing the environmental issue of large-scale waste tires disposal. How to handle the enormous amount of waste tires in Ethiopia has become an urgent environmental issue. Every year, many of tires are discarded. Because tires have a long life, disposal of waste tires is a challenge. The traditional technique of managing waste pneumatics was storage or illegal dumping or landfilling, all of which are a short-term solution. (Herna´ndez and Olivares, 2009)..

CR is used in hot mix asphalt as a replacement for parts of coarse and fine aggregate, resulting in a preference for gap gradations, and aggregate does not appear in the dimensions of the added CR. Furthermore, the work of designing a gradation curve of aggregate corresponding to the added rubber powder is quite complicated because the melting of fine CR particles will occur at high temperatures. The application of CR in hot mix asphalt is a promising solution, but problems of consistency in the characteristics of the mixes should be considered. (Herna´ndez and Olivares, 2009).

Whether it is processed in either the wet or dry approach, the crumbed rubber used in asphalt surfacing applications has several other advantages other than improved resistance to skidding. It also provides asphalt mixtures with high shear strength, which is favorable in withstanding imposed traffic load and preventing the occurrence of rutting in the underneath pavement layers. (Huang and Heidrich, 2007) (Mashaan and Karim, 2014) In addition, during freezing and thawing cycles in cold weather conditions, the presence of scrap rubber in the underneath layer compositions plays a crucial role in reducing the frost penetration level (Huang and Heidrich, 2007). Some other benefits of using crumbed rubber in road construction applications include but not limited to rendered temperature susceptibility, fostered rutting and fatigue resistance, and increased stability and reduced flow value (up to a rate of 10% of crumb rubber) and improving stripping resistance. (Modarres and Ayar, 2016). When added to asphalt binder up to a percentage of 30%, significant enhancement in properties such as weathering and stripping resistance have been achieved. (Huang and Heidrich, 2007)

2.1.8 Waste marble dust

Marble is a crystalline, compact variety of metamorphosed limestone transformed through the heat and pressure into a dense, variously colored, crystallized rock (Zewde, 2011) In Ethiopia, marble deposits are found in western part of Wellega (Daleti) and Gojam (Mora, Bulen, Mankush and Baruda) (Walle, 2000). Marble deposits are also found in the northern Ethiopia.

These marble deposits are different from that of the west in age, grain size and color (Zewde, 2011).

Marbles can be defined from different perspectives of view, like scientifically and commercially. According to these two perspectives, an all-natural stone created due to the recrystallization of limestone ($CaCO_3$), and that could be processed, polished, used for various construction purposes, and are of market value is known as marble (Aydin 2013). Marbles are extracted and transported from quarries in the form of the big block by using different mining techniques. These marble blocks, which are transported to the marble processing plant, are first to cut into large slabs. Then after the large slab surfaces are polished by machines and lastly polished slabs are cut down into the needed size and shape as required by customers (Demirel and Elmaci 2018)

Marble blocks are cut into smaller blocks in-order to give the required smooth shape. During the cutting process about 20% – 25% marble is resulted into dust, chips (Antiohas and Terzi, 2005) (Kumar, 2016). The use of such by-products also has an impact to the environment. Marble dusts are settled by sedimentation which results in ugly appearance and cause dust in the summer to threat both agriculture and health (Antiohas and Terzi, 2005).

Hence, the re-use of these materials is important.

Table 2.1 Physical Properties of Marble waste dust (mineralzone 2017)

Physical properties	Marble waste dust
Density	2.55-2.7 gm/cm3
Hardness	3 to 4 moh’s scale
Water absorption	<0.5%
Porosity	Very low
Weather	impacts Resistance

.

2.2. Effect of Mineral Fillers on Hot Mix Asphalt Concrete

Mineral fillers are added to asphalt paving mixtures to fill voids in the aggregate and reduce the voids in the mixture. However, addition of mineral fillers has dual purpose when added to asphalt mixtures. A portion of the mineral filler that is finer than the asphalt film thickness mixed with asphalt binder forms a mortar or mastic and contributes to improved stiffening of mix. This modification to the binder that may take place due to addition of mineral fillers could affect asphalt mixture properties. (Herna´ndez and Olivares, 2009).

Mineral fillers contain finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, loess, and other suitable mineral materials. Aggregate passing through 0.075 mm IS sieve is called as filler. It fills the voids, stiffens the binder and offers permeability (Mohanty, 2013). Mineral filler in hot mix asphalt is an essential component of the mixture as the design and performance of hot mix asphalt (HMA) concrete is greatly influenced by the nature and amount of the mineral filler in the mix, excess quantity of filler tends to increase stability, brittleness, and proclivity to cracking. Deficiency of filler tends to increase void content, lower stability, and soften the mix. (Bouchard, 2005)

The filler content is particularly important as it has a significant impact on technical properties and, hence on potential end use. The gradation, shape, and texture of the mineral filler significantly influence the performance of hot mix asphalt regarding permanent deformation, fatigue cracking, and moisture susceptibility. A better understanding of the effects of fillers on the properties of mastics and HMA mixtures is crucial to good mix design and high performance of HMA mixtures. (Eltaher, 2016)

filler have various purposes among which, they fill voids and hence reduce optimum asphalt content and increase stability, meet specifications for aggregate gradation, and improve bond between asphalt cement and aggregate (Bouchard, 2005)

The general overview of this study was to evaluate the suitability of new different fillers extracted from different local sources on the performance of asphalt mixtures. It was state that filler content has a considerable effect on the mixture making it act as a much stiffer, and thereby affect the HMA pavement performance including its fracture behavior. Hence from the above views it clearly understands that fillers are important components of Asphalt concrete mixtures. (Bouchard, 2005)

2.3. Gradation Specifications for Asphalt binder coarse

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage. Gradation is usually measured by a sieve analysis.

Authorities will often base the choice of particle size distribution on local experience or the recommendations of the Asphalt Institute.

Particle size distributions recommended by the Asphalt Institute for binder course layers are shown in table 2.1

Table 2.2: Gradation of Asphalt Binder Course (ASTEM 3515)

Sieve No	Sieve Size (mm)	Percentage by Weight. Passing	
		Min	Max
1"	25	100	100
¾	19	90	100
½	12.5	71	88
¾	9.5	56	80
No. 4	4.75	35	65
No. 8	2.36	23	49
No. 16	1.18	15	37
No. 30	0.6	10	28
No. 50	0.3	5	19
No. 100	0.15	4	13
No. 200	0.075	2	8
Bitumen content (%)		4	10

2.4. Volumetric Properties of HMA

In HMA mixture volumetric properties are the one which shall be determined to create sufficient performance for the pavement. Different researchers studied the effect of mineral fillers on the volumetric property of bituminous mixtures. Most of all concluded that mineral fillers have a strong relation with the overall volumetric property of HMA mixture.

HMA volumetric properties are necessary requirements to ensure a good performance, and these properties are directly influenced by the mixture grading, aggregates surface characteristics and compaction energy. The research also evaluated the mineral filler influence on the volumetric properties of HMA, the Voids in Mineral Aggregates (VMA) and Voids Filled with Asphalt (VFA)(Vivian Silveira and Santos B, 2013).

And this all volumetric parameters are highly influenced by the content of mineral fillers in the overall aggregate gradation. The different experiments to relate mineral fillers content with volumetric and performance parameters of asphalt mixture. The researcher summarizes the theoretical and experimental results of the study as follow: Adding glass powder of 6 % by total weight of aggregates on the hot asphalt concrete mixtures leading to increase the Marshall stability (Nathem A and Saffar, 2013)

2.4.1 Bulk Specific Gravity

The bulk specific gravity of a mixture refers to the specific gravity of a specimen of compacted mixture, including the volume of air voids within the mixture. It is equivalent to the mass of a given specimen in grams, divided by its total volume in cubic centimeters. The bulk specific gravity test on the freshly compacted specimens are performed as soon as when they have cooled to room temperature. (Bouchard, 2005)

To determine the bulk specific gravity of dense graded mixture, the compacted specimens are extruded from mold, cooled to room temperature, and the dry weight recorded. Each specimen is then immersed in water at 25° C for three to five minutes, and the immersed weight is recorded. The specimen is removed from the water, surface dried by blotting with a damp cloth, and the surface dry weight recorded in air AASHTO T166 Method A or ASTM D 2726 (ASTM, 1992).

2.4.2 Theoretical Maximum Specific Gravity

The theoretical maximum specific gravity often referred to as maximum theoretical density HMA density excluding air voids. Thus, theoretically, if all the air voids were eliminated from HMA sample, the combined density of the remaining aggregate and asphalt binder would be the MTD. MTD is a critical HMA characteristic because it is used to calculate percent air voids in compacted HMA and provide target values for HMA compaction. MTD is determined by taking a sample of oven-dry HMA in loose condition versus compacted condition, weighing it and then completely submerging it in a 25°C water bath. A vacuum is then applied for 15 minutes to remove any entrapped air. The sample volume is then calculated by subtracting its mass in water from its dry mass (ASTM, 1998).

2.4.3 Voids in the Mineral Aggregate

The voids in the mineral aggregate are defined as the inter granular void space between the aggregate particles in a compacted asphalt mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The VMA is calculated on the basis of the bulk specific gravity of the combined aggregate and is expressed as a percentage of the bulk volume of the compacted asphalt mixture. VMA is calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the volume of the compacted asphalt mixture. (Roberts and Kennedy, 2006).

VMA is an important factor for mixture design. Voids in the Mineral Aggregate must be sufficient to allow adequate effective asphalt which is not absorbed into the aggregate particles and air voids for its durability purpose, and air space. The more VMA in the dry aggregate, the more space is available for the binder. Since a thick binder film on the aggregate particles results in a more durable asphalt mixture, specific minimum requirements for VMA are recommended and specified as a function of the aggregate size. (Bruce, Eugene, and Benita 2007).

2.4.4 Air Voids in Compacted Mixture

Air voids are small pockets of air that exist within the asphalt binder and between aggregate particles expressed as percent of the bulk volume of the compacted paving mixture. (Zemichael 2007).

2.4.5 Voids Filled with Asphalt

Voids filled with asphalt are the void spaces that exist between the aggregate particles in the compacted paving asphalt mixture that are filled with binder. VFA is expressed as a percentage of the VMA that contains binder.

Including the VFA requirement in a mix design helps prevent the design of asphalt mixture with marginally acceptable VMA. The main effect of the VFA is to limit maximum levels of VMA and subsequently maximum levels of binder content. (Asphalt Institute, 2008).

2.5. Marshall Stability and Flow

Laboratory investigations on the mechanical performance of asphalt concrete mixtures have been conducted by using varying specimen bitumen content. The Marshall stability test (ASTM Designation: D 1559-82), is used in highway engineering for both mix design and evaluation. Although Marshall method is essentially empirical, it is useful in comparing mixtures under specific conditions.(Hassan Y, 2006) Therefore it was selected within this research to study the effect of adding waste mineral fillers in hot mix asphalt.

The Marshall stability value obtained is an indication of the mass viscosity of the aggregate-asphalt cement mixture. In most cases, it is affected significantly by the angle of internal friction of the aggregate and the grade of the asphalt cement. Hence, one of the easiest ways to increase the stability of an aggregate-asphalt mixture is to use a higher viscosity grade of asphalt cement (Jahanian and Shafabakhsh 2017; Qasrawi and Asi 2016). It is also possible to increase the stability of the mix by selecting a more crushed angular aggregate than rounded shape aggregates(Mohammad 2020). Study shows the incorporation of finest fillers which also have higher porosity and specific surface area provided higher stiffening in mastic, which in turn produced mixes with higher Marshall Stability. (Islam and Ransinchung 2020)

The flow is measured as the vertical deformation of the specimen in hundreds of inch from start of loading up to the point where the stability begins to decrease. It is obtained at the same time as the Marshal Stability test is conducted. Generally, high flow values indicate a plastic mix that is more prone to permanent deformation problem due to traffic loads, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and could result premature cracking due to mixture brittleness during the life of the pavement. (Vivian Silveira and Santos B, 2013)

2.5.1. Determination of OBC and OFC

There are a number of methods to select the optimum bitumen content once the data is arranged. Each agency that is involved with pavement construction has its own methods to selecting the optimum bitumen content. According to (ERA Manual, 2013). the following two methods are commonly used to select the optimum content. MS-2 Asphalt Institute Method.

The basic steps that are followed in determining the optimum asphalt binder are: Make several trial mixes with different asphalt binder contents, compact these trial mixes in the laboratory, run several laboratory tests to determine key sample characteristics then pick the asphalt binder content that best satisfies the mix design objectives. In this study selected mix design is usually the most economical one that will satisfy all of the established criteria stated in MS-2. However the mix should not be designed to optimize one particular property but should be a compromise selected to balance all of the mix properties (ERA Manual, 2013). Method 1 (MS-2) was selected for this research in order to determine the optimum asphalt content and for further mix design i.e. for Replacement of filler in a mix. The marshal properties of the asphalt mix, such as stability, flow, bulk density, air void in the total mix, and voids filled with bitumen were must be in the range of suggested marshal criteria for asphalt concrete mix design. (ERA manual, 2013).

In principle any of the wearing course or binder course grading described can be used as a running surface for traffic loading up to 5 million equivalent standard axial loads (ESA). The larger stone mixes have to be placed in thicker layers and the surface finish of such mixes will have a coarser texture. All mixes should be designed to the Asphalt Institute (MS-2, 1994) Marshall Criteria for wearing courses for Heavy (1 - 5); Number of blows of Marshall Compaction hammer 75 on both sides, Min. Stability (N) 8000, Flow (mm) 2-3.5, VFB (%) 65-75. (ERA Manual, 2013)

MS-2 is a better method of selecting the Marshall Design binder content is to examine the range of binder contents over which each property is satisfactory, define the common range over which all properties are acceptable, and then choose a design value near the center of the common range. If this common range is too narrow, the aggregate grading should be adjusted until the range is wider and tolerances become less critical (Freddy and Ray Brown, 2009). It is important to know that aggregate gradation is directly related to optimum asphalt content. The finer the mix gradation, the larger surface area of the aggregate and the greater the amount of asphalt required to uniformly coat the aggregates. Conversely, because coarser mixes have fewer totals aggregate surface area, and then require less asphalt.

2.6. Moisture Susceptibility

Moisture is a primary cause of failure of asphalt mix because its presence could lead to its loss of structural strength and durability (Mistry 2018). Moisture can damage the HMA in the following two ways: 1) loss of bond between the asphalt cement or mastic and the fine and coarse aggregate and 2) weakening of the mastic due to the presence of moisture. Six contributing factors have been attributed to causing moisture damage in HMA: detachment, displacement, spontaneous emulsification, pore-pressure induced damage, hydraulic scour, and environmental effects (Lowa 2010). Many test methods have been developed in the past to predict the moisture susceptibility of HMA mix. The test methods mentioned below are not the only ones and other tests are still being used throughout the world.

The presence of water in asphalt pavement is unavoidable. Several sources can lead to the presence of water in the pavement. Water can infiltrate the pavement from the surface via cracks in the surface of the pavement, via the inter-connectivity of the air-void system or cracks, from the bottom due to an increase in the groundwater level, or from the sides (Asres, 2013). However, water weakens the structure to a point where the mix can no longer sustain the traffic it was designed to support and finally fails under the repeated loading.

Moisture is a key factor in the deterioration of asphalt pavement moisture damage including aggregate, asphalt binder, type of mix, weather and environmental effects, and pavement subsurface drainage. One of the desirable properties of bituminous mixtures is that the resistance to moisture-induced damages. The resistance to moisture damage under the presence of moisture in the mixture is a complex matter, and the degree mainly depends on the properties of each ingredient material in the mixture, type and use of the mix, environment, traffic, construction practice, and the use of anti-strip additives. (Zemichael, 2007).

A commonly used test for this purpose is AASHTO Designation T 283 Standard Test for Resistance of Compacted Bituminous Mixture to Moisture Induced Damage (AASHTO 1997) and ASTEM 4867. In this test, a set of replicate specimens of the asphalt mixtures to be evaluated are compacted to 7 ± 1% air voids. The specimens are divided into two subsets. One subset is tested in the dry condition for indirect tensile strength. The other subset is subjected to vacuum saturation followed by a freeze and warm-water soaking cycle and then tested for indirect tensile strength. A mechanical displacement control testing frame was used to conduct the indirect tensile tests in accordance with (ASTM D4123) to evaluate the tensile strength of asphalt concrete mixtures.

The indirect tensile test was developed to determine the tensile properties of cylindrical concrete and asphalt concrete specimens through the application of a compression load along a diametrical plane through two opposite loading heads. It was shown (Kamil E, 2002). The tensile strength ratio, which is calculated by dividing the average tensile strength of the conditioned subset by the average tensile strength of the dry subset, is used as an indicator of stripping resistance.

2.7 Summary of literature

Currently, in Ethiopia and also in developed country amount of waste product of WMD and CR are rising day to day. This disposal of WMD and CR was causing various environmental problems. Numerous studies have been conducted to compare the suitability of alternative filler replacement in hot mix asphalt mixtures. WMD and CR filler is one of the alternatives to mineral fillers. The properties of hot mix asphalt depend on the quality of aggregate and bitumen, mix proportions and construction process. The study on physical and chemical properties of mineral filler and aggregate is most important effects of aggregate mineralogy in the performances of HMA. Its influence is on adhesion and moisture damage. Fillers are one of the most important ingredients of HMA that plays an important role in properties of bituminous mixture particularly in terms of air voids and VMA. Currently, there are numerous waste materials generated from different industrial and construction sectors that help researchers to choice optimum filler. Application of industrial products used as a filler material like (WMD, CR, ceramic waste dust, coal fly ash, steel slag) waste improves the engineering properties of hot mix asphalt mix. The reported improvement in the engineering properties of the paving mixtures containing WMD, CR, Coal fly ash, and Steel sludge filler can be attributed to the bonding and cementation properties of the fillers. Meantime deficiency of filler tends to increase void content, lower stability, and soften the mix. Despite there are many methods of asphalt mix design, the Marshall test method has may effective advantages. It is easy to use, portable, inexpensive, short testing time and requires less energy relative to others method. And besides of this, conducting asphalt performance tests like tensile strength test is also an important.

CHAPTER THREE

MATERIALS AND RESEARCH METHODS

3.1 Introduction

This study focused on the comparative suitability of WMD and CR filler as partially replacement of CSD on HMA. This chapter was describing the different procedures and test methods used in the study. Various activities are involved in answering the research questions and in attaining the objectives of the study. These activities were including material selection and characterization, preparation of mix design, evaluation of Marshall Properties of the bituminous mixture. Generally, all tests in this study are conduct in Jimma Institute of technology, Highway engineering Laboratory and in Ethiopian geological survey which is located in Addis Abeba.

3.2. Description of the Study Area

This research was conducted in Jimma town. Jimma is found in the south-western part of Ethiopia that is 345 km far from Addis Ababa, the capital city of Ethiopia. It covers a total surface area of 19,305.5 km2. Jimma is geographically located between 7° 38‘52” and 7° 43‘ 14” N latitude, and between 36° 48‘ 00” and 36° 53‘ 24” E longitude. In general, the topographical features elevation varies from 1780 to 2000 m above sea level with average maximum & minimum temperatures in the range of 25-30°C. It lies in the climatic zone locally known as Woyna-Dega. It was founded in 1837 E.C by the king of Abba Jifar

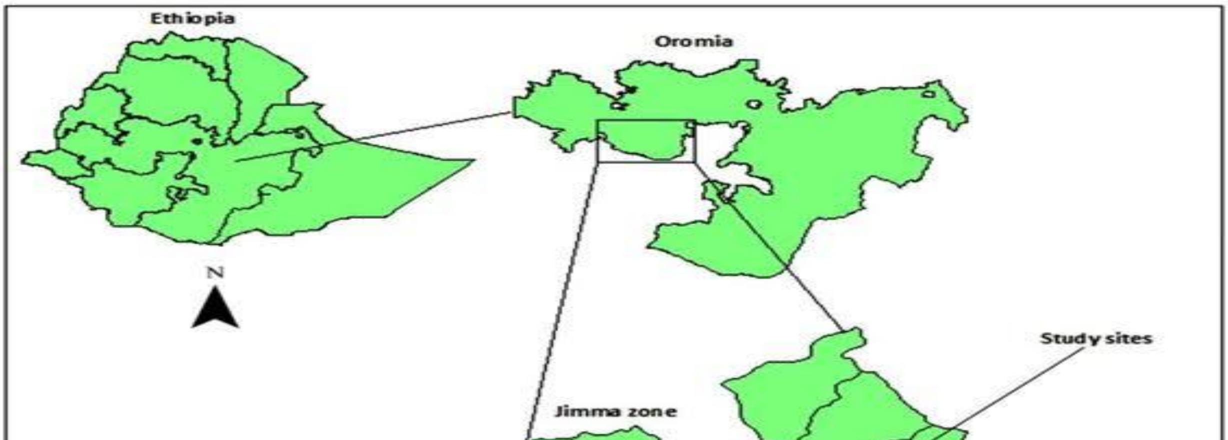


Figure 3.1 map showing the study area taken from google earth using Arc GIS

3.3. Research design

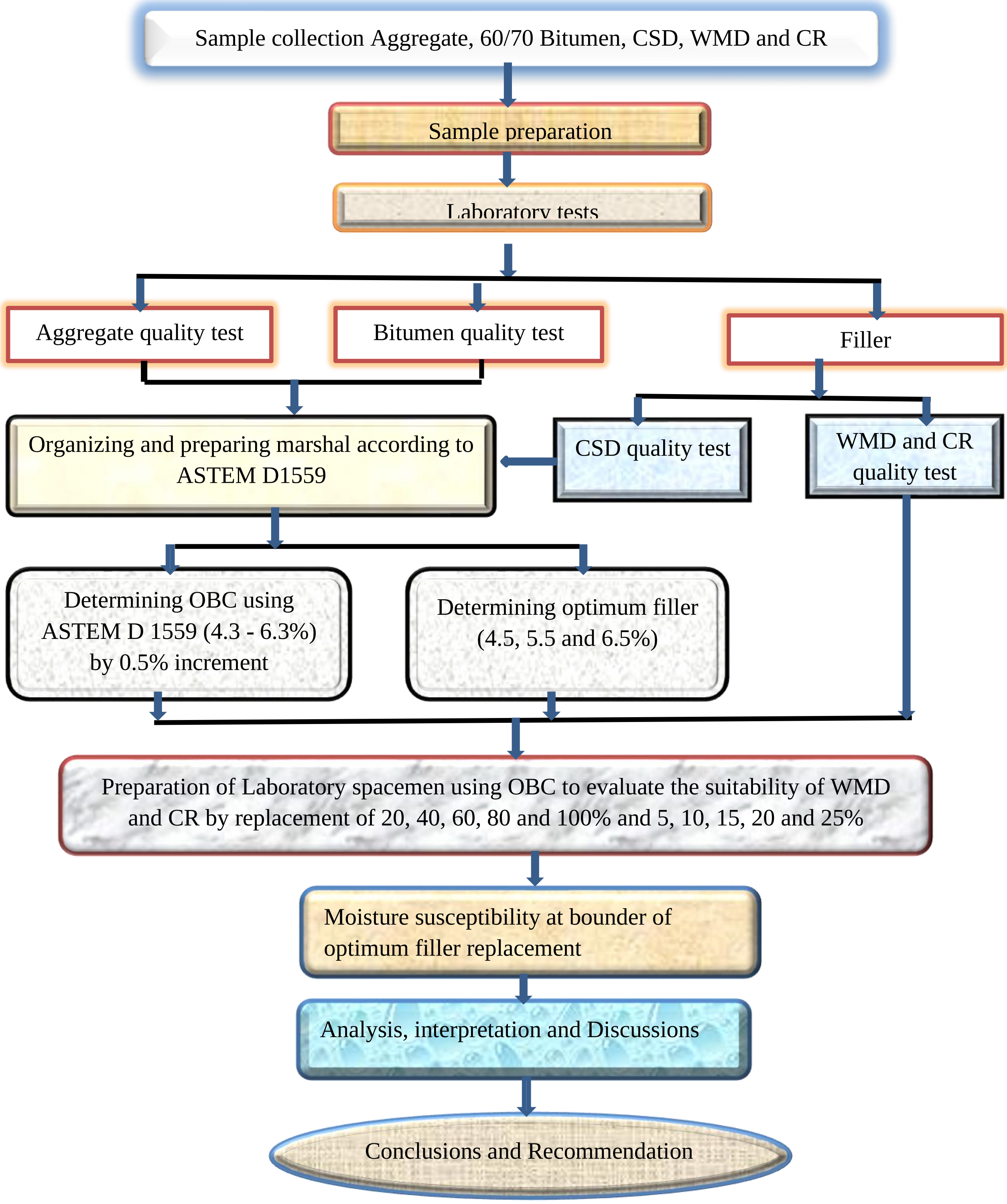
In order to achieve the goal of the study and for the development of concepts, which was basics for the formation of the overall study works as well as for the collection of required data, a comprehensive related literature review together with the experimental method was adopted

The study is designed to answer the research questions and meet its objectives based on experimental findings. It was performed as per AASHTO, ASTM, ERA and BS laboratory standards for all materials properties (asphalt binder, aggregates, and fillers).

Material selection and sample collection was carried out for the proposed HMA mix design from Ethiopian Road Construction Corporation quarry located at Danaba site 81 km from Jimma town. Accordingly, aggregate of different size and 60/70 bitumen penetration grade were collected. The site is selected from the viewpoint of the good quality material besides of its availability in nearest local site of the study area. Waste Crumb rubber was collected from Jimma town and marble waste also collected from the near construction site in Jimma town

The next work followed chemical property of WMD and CR, material selection and collection was quality tests for aggregates, bitumen and fillers. The aggregate quality tests conducted was: specific gravity, Los Angles abrasion, Sieve analysis (gradation), water absorption, flakiness index, aggregate crushing value and aggregate impact values. And bitumen quality tests conducted was: softening point, penetration test, ductility test, flashing and firing test as well as specific gravity test.

Figure 3.2. Research design process.



3.4. Sample Size

HMA samples were prepared with three different filler contents of CSD from 4.5, 5.5 and 6.5% by weight of total aggregate) and five different bitumen content (4.0 to 6.0% with 0.5% increment by weight of total mix) as per ASTM D1559 procedure. The samples were subjected to Marshall Stability test and aimed to obtain the proper OBC with its respective OFC based on maximum Marshall Stability. Then, CSD was replaced with CR and WMD at replacement percent of 0, 5, 10, 15, 20 and 25% and 20, 40, 60, 80 and 100% by the mass of CSD respectively. The replacements were performed on the best fit selected gradation, OBC and OFC. Then, stability, flow and volumetric properties were determined. For this study the total of 120 specimens were prepared including moisture susceptibility test. Seventy-eight (78) of these specimens were done for Marshall test and out of these 33 specimens were executed for partial replacement.

3.5. Dependent and independent Study variables

3.5.1 Dependent variables

The dependent variable of this study was suitability Crumb rubber and Waste Marble Dust on suitability of Hot Mix Asphalt.

3.5.2 Independent Study variables

The independent variables of the study was the proportion of aggregate sizes, percent content of CR, WMD and CSD, laboratory tests aggregate crushing value, aggregate impact value, loss angles abrasion value, specific gravity of aggregate, elongation index, and flakiness index, asphalt binder, filler content, Optimum Bitumen Content (OBC), Voids Filled with Asphalt (VFA), Void in Mineral Aggregate (VMA), Bulk Density, Marshal Stability, Penetration Value, Ductility Value, and Softening Point etc.

3.6. Data processing and analysis

The study is conducted in performing physical properties and characteristics of aggregate, asphalt binder/bitumen, and filler material through laboratory tests. Subsequent to ensuring the quality of material preparation of specimen are performed in order to determine the design gradation, the optimum content of both filler and bitumen through the marshal properties and volumetric properties of each sample were determined. Data are analyzed and processed using graphs and tables, and the test result comparison made with a standard specification of the Binder course on the ERA pavement design manual was be an important aspect of the analysis. The result obtained is organized and interpreted using Microsoft office word and MS-excels according to set objective and presented as chart, table and graph.

3.7. Experimental Procedure (Experimental setup)

This study is to evaluate suitability of the use of WMD and CR as filler material dust in hot mix asphalt concrete. The suitability of WMD and CR evaluated by preparing laboratory samples with different percentages of the primary conventionally used crushed stone dust filler were replaced with the waste marble dust and crumb rubber and Marshal Stability, flow, and volumetric properties evaluated by the method of Marshall mix design.

In this research work, aggregates with different gradations stone dust as filler and bitumen (60/70) as filler was used, In HMA mixture gradation is considered as the cornerstone property of aggregate which needs careful attention due to its effect on mix properties and performance of HMA mixtures, including air void, stability, stiffness, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage (Abukhettala, 2006).The mix design of this research started with selection and evaluations of different size of aggregate, bitumen grade and filler materials. Beside of this, analysis of chemical properties of crumb rubber and waste marble composition was done in Ethiopian geological survey laboratories.

3.7.1 Materials selection and characterization

The mix design of this research started with selection and evaluations of different size of aggregate, bitumen grade and filler materials. Accordingly, aggregate materials and binder selection was carried out for the proposed HMA mix design from Ethiopian Road Construction Corporation quarry located at Danaba site 81 km from Jimma town. The site is selected from the viewpoint of the good quality material besides of its availability in nearest local site of the study area.

After selection of materials, different quality test of all collected materials was conducted based on international and local standards The quality tests are required to evaluate whether or not the selected materials meet the mix design requirement. Selection and characterization of individual ingredients are extremely significant to provide the required quality and properties of the prepared mix in the HMA mix design and production proportioning. A material was subjected to various tests in order to assess their physical characteristics and suitability in the road construction. The overall mix design procedure starts with the evaluation and selection of aggregate and bitumen sources. The individual ingredients of the mixture are tested in the laboratory in order to decide if they meet the specified requirement or not. A different material quality test was performed as per set by AASHTO, ASTM, and BS standards. The quality test which was carried out on aggregate, including mineral filler, were sieve analysis (gradation), aggregate crushing value, Los Angles abrasion, aggregate impact value, and specific gravity and water absorption test. Besides, bitumen quality tests, namely specific gravity, softening point, ductility, penetration, and flash point, were conducted to determine its quality.

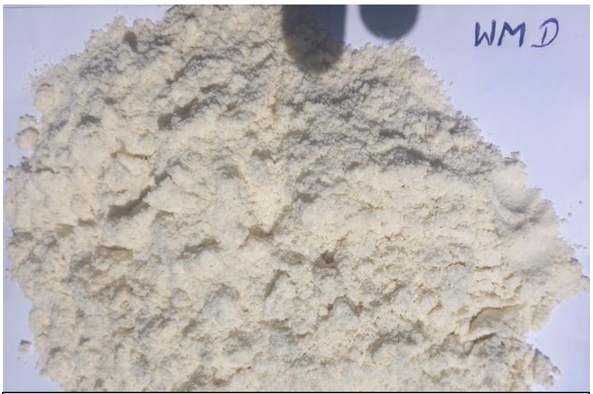
3.7.2 Physical properties of mineral fillers

In this research crumb rubber and waste marble dust from industrial as well as construction work were partially replaced with CSD as filler in HMA.

A/ Waste marble dust as filler

WMD was collected from the nearby construction site in Jimma institute of Technology as well as Marble distribution shop center in Jimma town. Then, manual grinding was performed on the dried conglomerate in order to obtain its dust which pass number two hundred (#200) sieve size. This waste marble collected as shown in as Figure 3.3

Waste marble collected around of Jimma town



WMD passed 0.075 mm (Captured.by:

Figure 3.3 Waste marble collected and WMD taken from my phone

B/ Crumb rubber as filler

CR was collected from local on Jimma town. And this solid waste burnt with uncontrolled temperature. Then the ash was subjected to physical tests like plasticity index, specific gravity, sieve analysis as well as chemistry test as shown in Table 4.1 and 4.2. CR is a non-plastic material as indicated in appendix A. This CR collected as shown in as Figure 3.4

Collected waste rubber (Captured by: Haile) | CR passed 0.075 mm (Captured by: Dajane)

Figure 3.4 Waste Crumb Rubber collected and CR taken from m

3.7.3 Aggregate

Some of tests were performed on mineral filler to show the physical characteristics that are believe to be considerable value in evaluating mineral fillers. The tests were conducted on filler, such as Sieve Analysis (AASHTO T 27), Sand Equivalent (AASHTO T 176), Plasticity Index (AASHTO T 89), Specific gravity (AASHTO T 85), Water absorption (AASHTO T 85), Los Angles abrasion (AASHTO T 96), and Flakiness index (%) (BS 812 Part 105), Soundness loss by $NaSO_4$ (AASHTO T 104), Aggregate Crushing Value (BS 812 Part 110) and Ten Percent Fines Value (BS 812 Part 111) With respect to the methodological choice for this study, laboratory test has used. It is very common to conduct using crushed stone dust as mineral fillers on the fillers before using them in any road construction in order to determine their physical properties whether they can meet or not the specification limits. Many properties of filler are needed in designing the pavement mixes. According to AASHTO standard, the mineral filler needs to be non-plastic and the plastic index is less than four.

3.7.4 Bitumen

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Binder provides durability to the mix. The asphalt binder used in this study was penetration grade of 60/70. In order to evaluate the bitumen properties laboratory test conduct. The bitumen quality tests of this research may conduct Penetration (ASTM D 5), Specific gravity (ASTM

D 70), Ductility (ASTM D 113), Flash point (ASTM D 92), Softening point (ASTM D 36) and Solubility in Trichloroethylene (ASTM D 2042). The physical properties of asphalt binder were determined according to the procedure specified by AASHTO standards.

3.7.5 Preparation of Marshall samples

The preparation of Marshall Specimen is the series tasks of experimental procedure guided by standards. Firstly, the blended aggregates having total weighing of 1180gm (for a single specimen) was heated in an Oven to a temperature of 155 to 170 °C for above 8 hours Then, the asphalt binder also heated at 155 to 165°C and added to the pre-heated aggregate and mixed thoroughly at desired temperature of 160°C (from 130-165°C for 60/70 bitumen grade) for two minutes. Next, after placing a paper disc in the mold, the mixed sample is poured into a mold. And then another paper disk is placed on the top of the mix. Afterward, the mixture is compacted with a compaction effort of 75 blows on each side by a 4.5kg hammer freefalling from 457mm height. After compaction, the specimens were put to cool for some hours (over 12 hours). And later, it was removed from the mold with the help of extruder. Then, the height of specimens, dry mass in air, sub-merged weight and saturated surface dry mass were taken. After that, the Marshall Stability and flow were tested following the removal of the specimen from immersed in water bath at 60˚C for 30 ± 5 minutes as per ASTM D1559 and witnessed in Figure 3.5

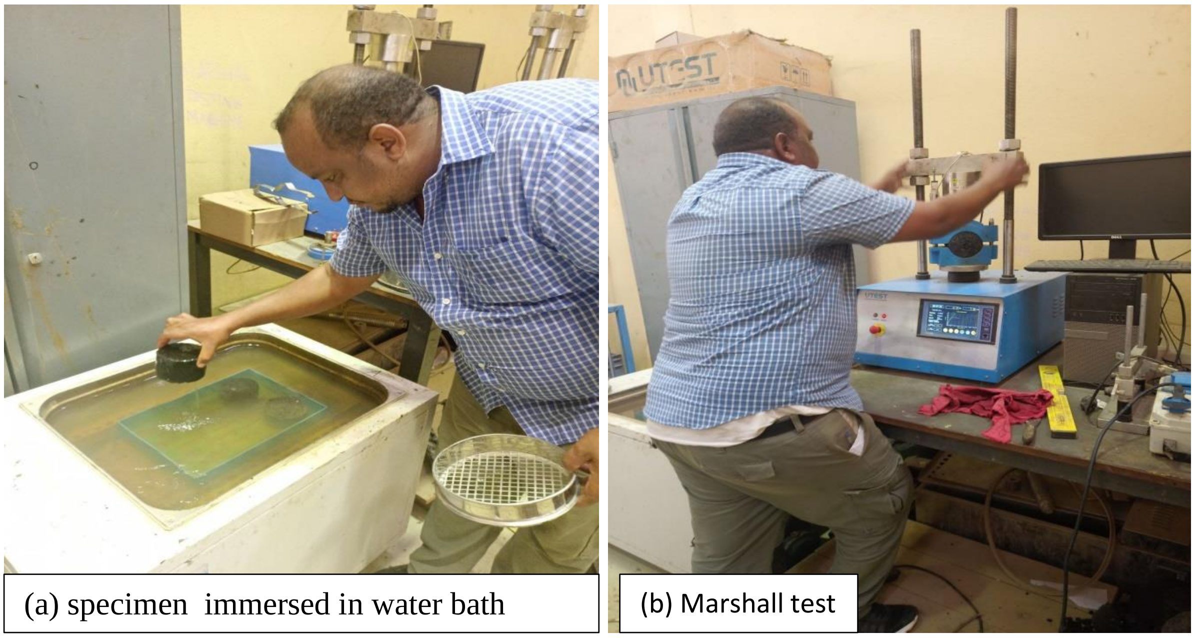


Figure 3.5 (a) specimen immersed in water bath, (b) Marshall test captured by Biniyam B.

In this research, laboratory work is conducted to determine the optimum asphalt content and optimum filler using the marshal method. To proceed with the marshal mix performing tests on material according to ASTMD1559 and five different bitumen content (4.3 - 6.3%) with 0.5% increment used. Depending upon the type of mineral filler in this study conventional filler material was inert filler material such as crushed stone dust, marble dust, etc. from thus, crushed stone dust are used as conventional filler material. According to ASTM inert filler material used as filler in HMA, to determine the optimum bitumen content and the optimum filler content, conventional filler (crushed stone dust) are used. Then using a different percentage of conventional filler and bitumen/asphalt binder, the mix design was performed through laboratory tests. Thus laboratory tests are Stability (KN), the flow value (mm), unit weight (gm/cc), VMA (%), VTM (%) are determined. From thus results, optimum bitumen content was determined. In addition, the maximum stability and lower flow value are used for the determination of optimum filler content. After determining the optimum bitumen content was proceeding the remaining test using the optimum bitumen content and the optimum filler are replaced with varying percentages of WMD and CR in 0% (control mix) 100%, 80%, 60%, 40, 20% and 5, 10, 15, 20 25% respectively. Then comparison was conducted in order to investigate the effect of non-conventional filler WMD and CR in HMA, and the result are evaluated with ERA standard specification for wearing course material.

3.7.6 Determining Optimum Bitumen Content

Optimum bitumen content of HMA mixture can be determined by two methods commonly used. These methods are MS-2 and NAPA (National Asphalt Pavement Association) procedure. For this study, the MS-2 (Asphalt Institute Method) procedure is used. Because is usually the most economical one that was satisfy all of the established criteria stated in MS-2.

Asphalt content corresponding to specification's median air void content (4 % typically) is the Optimum Asphalt Content. These methods mainly based on the plots were prepared using different volumetric properties with asphalt content. From this method optimum asphalt content is determined by:

1. The asphalt content which corresponds to the specification's median air void content (4 percent typically) of the specification. This is the optimum asphalt content.
2. The asphalt content is then used to determine the value for Marshall Stability, VMA, flow, bulk density and percent voids filled from each of the plots

3. Compare each of these values against the specification values for that property, and if all are within the specification range, the asphalt content at 4 percent air voids is optimum asphalt content. If any of these properties are outside the specification range, the mixture should be redesigned.

However, the mix should not VIM at optimum bitumen content (%) be designed to optimize one particular property but should be a compromise selected to balance all of the mix properties the design criteria and the range of bitumen content over which compliance with the criteria is achieved: that the addition test results confirm that the bitumen content giving 4 percent VIM is acceptable, that a design Optimum bitumen content would minimize the risk of plastic deformation and that the aggregate particle size distribution should be adjusted further away from the maximum density line to give slightly more VMA (ERA Manual, 2013).

3.7.7 The mix design replacement method of the study

After completing determination of OBC, the intended partial replacement of CSD with WMD and CR was undertaken. The mean values and standard deviations of each Marshall parameters were computed. And the study was made on comparative effect of WMD and CR in the replacement. The general steps followed by partial replacement were:

i) The WMD and CR were collected;

ii) Burning of the CR and cleaning as well as grinding of marble waste were undertaken;

iii) the replacement percent of each filler was determined (based on studied properties of the materials and by referring different literatures on the issues);

iv) The replacements of CSD with WMD and CR were made and added to the blended aggregates and heated to a temperature of 155 to 165 °C prior to adding bitumen;

v) Bitumen was heated between 150 to 165°C before adding to the blended aggregate specimen and the standard Marshall Mold were also heated to 150 to 165 °C

vi) then, the determined 4.85% of OBC was added to the heated aggregate and mixed thoroughly until a homogenous mixture is obtained;

vii) the hot mixture is poured into the mold and subjected to 75 blows of compaction efforts on each face of the specimen after packing the mold by non-absorbent filter paper in each side.

In general, the preparation of the Specimens, compaction, and testing were done as per ASTM D 1559 Marshall Standard.

3.7.8 Density and void analysis

Density-void analysis is one of the tasks that should be performed to the compacted specimen after determination of height and masses of the specimen in different condition. In this section, volumetric properties which determine the performance of asphalt mixes were discussed.

i) The bulk specific gravity of compacted specimen

Bulk specific gravity is the ratio of the mass in air of a unit volume of permeable material. It includes both permeable and impermeable voids normal to the material. And it takes place at a stated temperature to the mass in the air (of equal density) of an equal volume of gas-free distilled water. The bulk specific gravity determination was performed on the compacted specimens after it extruded from the mold. Normally this value is utilized to determine the mass per unit volume of the compacted mixture. In this study, the bulk specific gravity of compacted mixtures was determined by using saturated surface dry specimen as per AASHTO T 166/ ASTM D 2726. The standard bulk specific gravity test is expressed as:

$$Gmb = (A/B-C) \quad (1)$$

Where: Gmb= Bulk specific gravity of compacted specimen, A = Mass of the dry specimen in air, g, B = Mass of the saturated surface-dry specimen in air, g, and, C = Mass of the specimen in water (Freddy and Ray Brown, 2009)

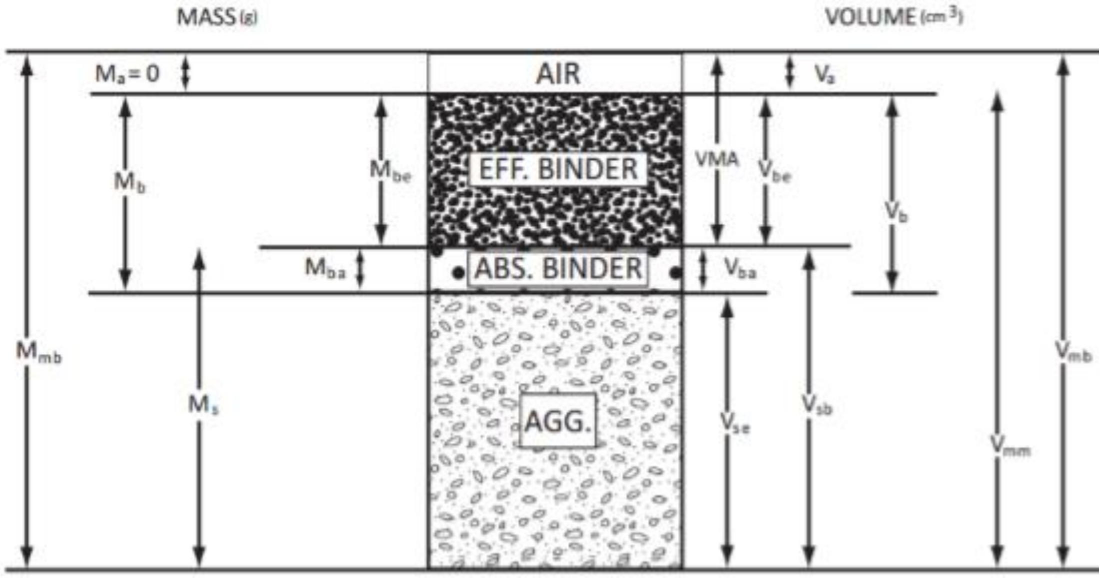


Figure 3.6 Representation of volumes in a compacted HMA specimen

VMA = Volume of voids in mineral aggregate V b = Volume of asphalt binder

V mb = Bulk volume of compacted mix M s =mass of total aggregate

V mm = Void less volume of paving mix Mb = mass of asphalt binder

V ba = Volume of absorbed asphalt binder M s= Mass of aggregate

V sb = Volume of mineral aggregate M air = Mass of air = 0

M be = Mass of effective asphalt binder and M ba = Mass of absorbed asphalt binder

ii) The theoretical maximum specific gravity of loose specimen

The Bulk specific gravity and the theoretical maximum specific gravity of an asphalt concrete are essential in order to determine the volumetric properties of hot mix asphalt mixture. These volumetric properties are one of a good indicator of the asphalt concrete performance.

The mixed sample allowed cooling down at room temperature for 24hours and the bulk specific gravity was done at 25˚c according to ASTM 2726. For each sample mass in the air, mass of sample in water and mass in surface saturated sample were measured. The theoretical maximum specific gravity of an asphalt concrete mixture is the specific gravity of the mixture at zero air void. This maximum specific gravity is determined by measuring the specific gravity after removing all of the air interrupted in the mixture by subjecting the mixture to a partial vacuum saturation. The maximum specific gravity of the mix conducted according to ASTM D 2041 method as fig 3.7

(a) Mixing spacemen of GMM | (b) Spacemen cooling down | (c) Removing air

Figure 3.7 (a) Mixing spacemen of GMM, (b) Spacemen cooling down, (c) Removing air

It is defined as the ratio of the weight in air of a unit volume of loose asphalt mixture at a stated temperature to the weight of an equal volume of gas-free distilled water at a stated temperature. The theoretical maximum specific gravity (Gmm) at various asphalt binder content was used to determine the air void percentage in the mix. Experimentally it could be determined as

$$Gmm = (A/A+B-C) \qquad (2)$$

Where: Gmm= Maximum Theoretical Specific Gravity is calculated as per ASTM D 2041, A = Mass of the dry sample in air, g, B = Mass of Jar Filled with Water, g, and C = Mass of Jar Filled with Water + Sample, g.

iii) Air void (VA)

Air voids are small air space or pockets of air that occur between the aggregate particles in the final compacted asphalt mixture. A certain percentage of air voids is necessary for all dense-graded mixes to prevent the pavement from flushing, shoving, and rutting. Air void may be increased or decreased by lowering or raising the binder content. They may also be increased or reduced by controlling the amount of material passing the No. 200 sieve in the asphalt mixture. The finer added to the asphalt mixture generally the lower the air voids. Finally, the air void may be changed by varying the aggregate gradation in the asphalt mixture (Asphalt Institute, 2008)

According to Asphalt Institute, (2003), the total compacted paving mixture consists of the small air spaces between the coated aggregates particles. The voids in a compacted mixture are obtained in accordance with ASTM D3203- 94 standard test method. The voids in a compacted mixture are obtained as follows.

VA= (Gmm-Gmb/Gmm) (3)

Where: VA = Air voids in compacted mixture and Gmb= bulk specific gravity of compacted mixture.

iv) Voids in mineral aggregates (VMA)

According to Asphalt Institute, (2003), the voids in the mineral aggregates, are defined as the inter-granular void space between the aggregate's particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percent of the total volume of the sample. The VMA are calculated based on the bulk specified gravity of the aggregates. And is a percentage of the bulk volume of the compacted paving mixture. It is calculated as:

VMA= (100-Gmb/Gsb*Ps) (4)

Where: VMA = voids in the mineral aggregate, Gsb = bulk specific gravity of total aggregate and Ps = aggregate content, percent by mass of total mixture.

v) Voids filled with asphalt (VFA)

According to Asphalt Institute, (2003), VFA is the percentage portion of the volume of inter-granular Void space between the aggregate particles that is occupied by the effective asphalt. It is expressed as the ratio of (VMA-VA) to VMA. VFA is the percentage of the integral void space between the aggregate particles (VMA) that are filled with asphalt. The mathematical relationship has shown as:

VFA= (100*(VMA-VA)/VMA (5)

Where: VFA = Voids filled with asphalt, percent of VMA and VMA = Voids in mineral aggregates, percent of the bulk volume.

3.7.9 Moisture Susceptibility of Mixtures

The moisture sensitivity tests to identify the HMA mixture's ability to resist water damage and determines the degree of moisture damage. The test followed the as AASHTO T283. The two sets of compacted samples with (100 mm diameter and 75 mm long) were subjected to a tensile strength ratio tests, they are conducted by preparing six Marshall Specimen for each mix at optimum asphalt content of CSD, WMD and CR fillers. For each six samples are then divided into two groups of three specimens as control and the other three specimens are conditional test, the control group was stored at room temperature for four hours. The conditional test group were immersed in water at 60 ^{0}c for 24 hours and then moved to a water bath at 25^{0}c for two hours. Then tensile strength ratio is calculated accordance with ASTM D-4867, which should be a minimum of 0.8 or 80% as adopted by (ASTM D-4867).

The tensile strength ratio (TSR) result from the tensile strength test commonly used to evaluate the moisture sensitivity of the asphalt mixes. Therefore, in this thesis work, tensile strength ratio test used to determine the moisture induced damage properties of the asphalt mixture and witnessed in Figure 3.8

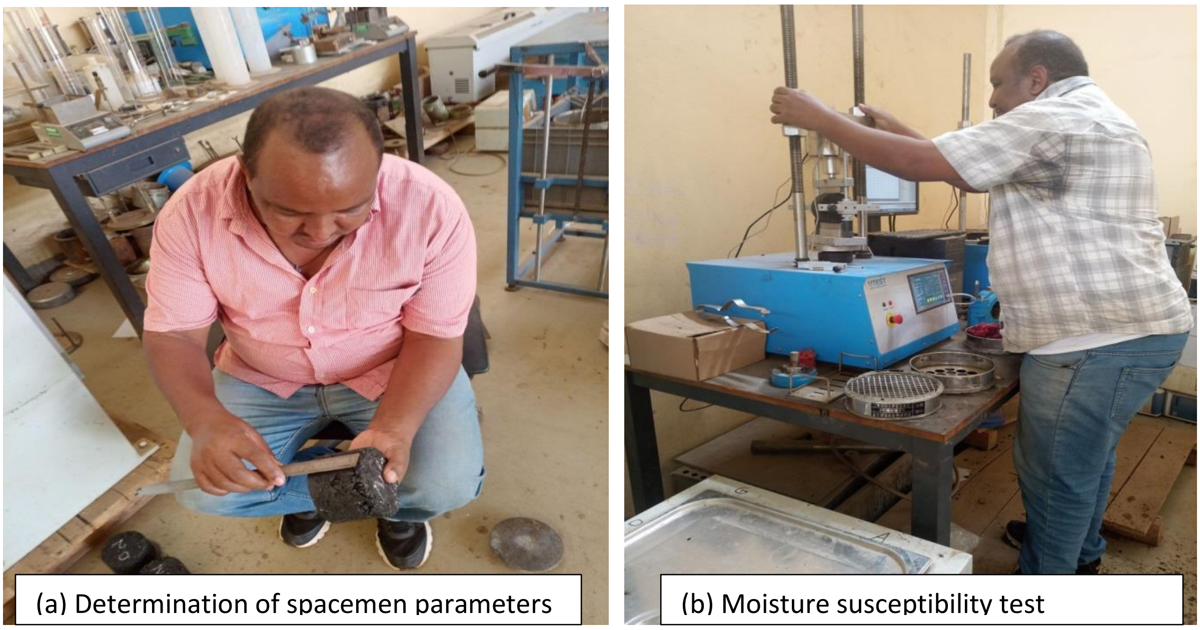


Figure 5.8 (a) Determination of spacemen parameters (b) Moisture susceptibility test (captured by Bimiyam B.)

The tensile strength result calculated as follow:

$$St = \frac{2000P}{\pi t D} \qquad (6)$$

Where: S_t= tensile strength (Kpa)

t= specimen thickness (mm)

P=maximum load (N)

D= specimen diameter (mm)

Tensile Strength Ratio (TSR) = $\frac{St2}{St1}$ (7)

Where: S_{t1} = average tensile strength of unconditioned or dry subset

S_{t2} = average tensile strength of conditioned subset

The tensile strength ratio (TSR), which is the ratio of the average split tensile strength of the conditioned (wet) sample over the average split tensile strength of the control (dry) sample, is satisfy the specific recommended requirement (TSR ≥ 0.80) AASHTO T283

The indirect tensile strength test is used to determine the tensile properties of the hot mix asphalt which can be further related to the moisture susceptibility hence indirect tensile strength ratio values were calculated, by using this equation of St tensile strength (kPa) equal to two thousand times maximum load (N) divided to π times thickness (mm) (t) times diameter (mm) (D). The resistance to moisture damage is a ratio of the unconditioned sample tensile strength retained after the conditioning.

The TSR was calculated using this equation. TSR equal to the average tensile strength of the conditioned samples (S_2) over average tensile strength of the unconditioned samples (S_1) Where TSR is the tensile strength ratio provide (> 80%) (ASTM D - 4867)

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Engineering properties of materials

4.1.1 Chemical properties of CR and WMD test results

The chemical compositions of aggregate fillers are specified in terms of oxides, unrelatedly of whether such oxides are present in the sample. It is chemical properties of aggregate fillers that undergo due to chemical action. It plays significant role in HMA performances as asphalt cement resist stripping of the asphalt films in the presence of water. But, different literatures signify that it has little effects on suitability and performance of aggregates fillers, except as they affect adhesion of asphalt binder to the aggregate. The oxide composition obtained from the Chemical Analysis of CR and WMD is summarized in Table 4.1.

Table 4.1 Oxide compositions of WMD and CR

Sample Chemical Composition (Weight %)								
Oxide	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	SO_3
WMD %	52.44	7.15	12.51	2.07	7.51	4.23	0.61	1.92
CR %	47.33	9.96	11.78	2.33	14.44	4.07	1.43	2.66

It was observed that SiO_2 has the highest composition in both powdered the oxide composition of WMD shows that it contains 52.44% silica which is higher than 47.33% for CR. The chemical test results of an experimental study for the pozzolan marble dust and crumb rubber were determined and compared with the ASTM C-618. The chemical composition or Pozzolanic property of WMD and CR materials was shows the major natural pozzolanic components of silicon dioxide (SiO_2), aluminum oxide(Al_2O_3), and iron oxide (Fe_2O_3) are 52.44%, 12.51% and 7.15 for WMD and 47.33%, 11.78% and 9.96% for CR which indicates that the two samples is a good pozzolanic materials. The composition of SO_3 found in WMD and CR material to be 1.92 and 2.66% respectively which is less than the 4% of the specified maximum requirement. Hence it can possible to replace CSD and used as a mineral filler in HMA design.

4.1.2 Physical Properties of Mineral Filler Test Results

Laboratory tests have been conducted in order to evaluate the physical properties of each type of filler, which consist of the gradation parameters, plasticity index and apparent specific gravity. This test was conducted according to ASTM D-854 using Water Pycnometer method. Table 4.2 shows, WMD, CR and CSD fillers are passing the sieve number 30, 50 and 200 which is accepted with the range specified by ASTM D242. Crushed stone dust is prepared from rock dust; WMD and CR are free from organic impurities and by using cone penetration test result of plastic index not greater than four. Hence CSD, WMD and CR are non-plastic (NP), the apparent specific gravity of CSD being 2.64, WMD 2.70 and CR 2.53 the test results indicated CR are slightly lower than CSD and WMD. It occurred because of difference in absorption capacity of the materials that depend on their porosity. And also it is noticeable that the higher absorption capacity material has lower specific gravity and higher surface area.

Table 4.2 Illustrate the Physical properties of the fillers.

Sieve No.	% Passing			ASTM D242
	CSD	WMD	CR	
No. 30	100	100	100	100
No. 50	100	100	100	95-100
No. 200	100	100	100	70-100
Plasticity Index	NP	NP	NP	< 4
Apparent specific gravity	2.64	2.70	2.53	--

4.1.3 Physical Property of Aggregate

Aggregate affects almost all the properties of hot mix asphalt concrete. The properties of asphalt concrete that can be affected by aggregates are stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. So, in order to obtain a good quality asphalt mix design, it is must to study the aggregate properties properly. The design of aggregate proportion is the output of trials based on local or international standards. The output of the quality tests is presented in the table 4.3

Table 4.3 Physical properties of aggregates on laboratory results and the specification

Test	Test Method	Test Results			ERA 2002 specification requirement
		Coarse Aggregate	Intermediate Coarse aggregate	Fine Aggregate	
Bulk dry S.G	AASHTO T 85-91	2.627	2.58	2.64	
Bulk SSD S.G		2.635	2.607	2.67	
Apparent SG		2.648	2.652	2.73	
Water absorption,%	BS 812, Part 2	0.304	1.046	1.25	< 2
Aggregate Crushing Value, %	BS:812 Part 110	17.73			< 25
Aggregate Impact Value, %	BS:812 Part 112	8.30			< 25
Los Angeles Abrasion, %	AASHTO T96	10.45			< 35
Flakiness index	BS812Part105	36.94			< 45

Specific gravity of aggregate normally used in road construction ranges are about 2.6 to 2.9 so this result is between the ranges hence it is acceptable. The result of aggregate crushing value is 17.73% it indicated that used for asphalt mixture because it's crushing value is less than 25% it is more acceptable or desirable. The result of aggregate impact value 8.30 is less than 25%. Hence it is exceptionally strong and also used for bituminous macadam surface course as well as water bound macadam surface, base and sub base courses. Los Angeles Abrasion or wear percentage of aggregate after 500 revolutions test is 10.45% this result indicates that all aggregate materials conform to specification so it can use the aggregate material for HMA and for bitumen concrete surface course because it is not exceed 30%. The flakiness index value calculated is 36.94 which is less than 45% hence it is acceptable and it can be used for hot mix asphalt material.

Apparent specific gravity of course, intermediate and fine aggregate are highest result value than bulk specific gravity and saturated surface dray specific gravity due to its measurement only the volume of aggregate particles that means is not include volume of any water.

4.1.4 Bitumen Quality Test

Result for the performance of this study, a series of bitumen quality tests were conducted before the mix design was started. These tests included penetration, ductility, softening point, Flashpoint, and specific gravity, and the test result was indicated in Table 4.4. The result of the bitumen quality test was meet the standard specification of selected bitumen of 60/70 penetration grade according to ERA,2013 pavement design manual standard specification the details of the test shown in Appendix B.

Table 4.4: Physical Properties of Bitumen

Test Type	Test Method	Av. Test Result	Qualification requirement ERA, 2013
Penetration (25^{0}C,100g) (0.1 mm)	ASTM D5-IP49	64.02	60 - 70
Softening point (^{0}C)	ASTM D36	51.4	46 - 56
Ductility (25 ^{0}C) (cm)	ASTM D113	93.7	Min. 50
Flash Point (^{0}C)	ASTM D 92	290 ^{0}C	Min. 232
Specific Gravity	AASHTO-T228	1.043	1.010-1.060

4.2 Marshall Properties of Asphalt mixes

The Marshall Properties of the study design are presented as in Table 4.5, 4.6 and 4.7 with its respective different filler contents. The parameters were: Gmb, VA, VMA, VFA, stability and flow. the values of VA decreased with an increased in bitumen contents. This is due to an increased in Gmb of the compacted mixes as the binder occupies the space available for further densification under traffic. And this may leads to over-asphalted mix design that susceptible to rutting. So the design of VA is a crucial issue in the mix design since it can easily affect other Marshall parameters. In other words, the decrease in VA as bitumen content goes higher and higher again leads to an increase in Marshall Flow which is the indicator of resistance in plastic deformation of the mix. Thus, Marshall Flow increase with an increase and decrease in binder content and VA of asphalt mixtures respectively. The VMA decreased with an increased in bitumen contents from 4.3 - 6.3%. This could be due to the increase in effective binder that causes the decline in VA of the total mix. In the same way the value of stability increased up to certain peak point and then decreased as percent of binder contents increases. The increased in stability indicates an improved in adhesion between aggregate and the binder that strongly resist rutting and shoving under traffic. In other words, an excess in the binder results in low stability of the mix design since stability can be affected by internal frictions and cohesion of the binder. Thus, as indicated in Figure 4.1, 4.3 and 4.5

The laboratory work result of asphalt mix laboratory work was obtained and analyzed to achieve the research objectives. Marshall Test results of the mixtures with different bitumen content and with different mineral filler content are presented in table 4.5, table 4.6 and Table 4.7. Further details are presented in Appendix C. Totally Forty-five specimens were prepared to determine optimum bitumen content and optimum filler content

Table 4.5 Marshall Properties of asphalt mixes conducted for OBC determination at 4.5% CSD

Bitumen content (%)	Bulk SG (Gsb)(Kg/m3)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4%	2.341	5.269	13.600	61.259	9.170	2.930
4.50%	2.356	3.535	13.500	73.813	10.917	3.250
5%	2.355	3.140	14.000	77.573	11.980	3.290
5.50%	2.353	2.144	14.500	85.212	10.870	3.450
6%	2.349	2.011	15.100	86.683	9.880	3.700

According to the chosen method which was MS-2 mix design method, it was specified as figure 4.1 this Common Ranges of mixture at 4.5% conventional filler (CSD) is 4.4 ~ 5.0% bitumen content, Hence Optimum Asphalt Content at 4.5% filler is 4.7%

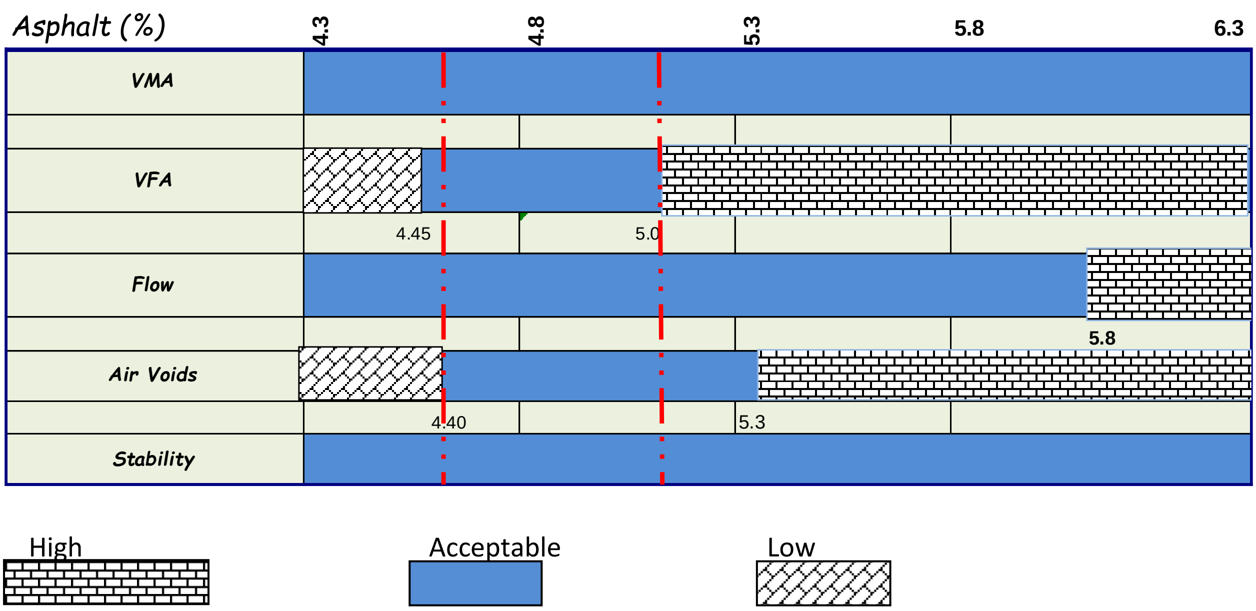
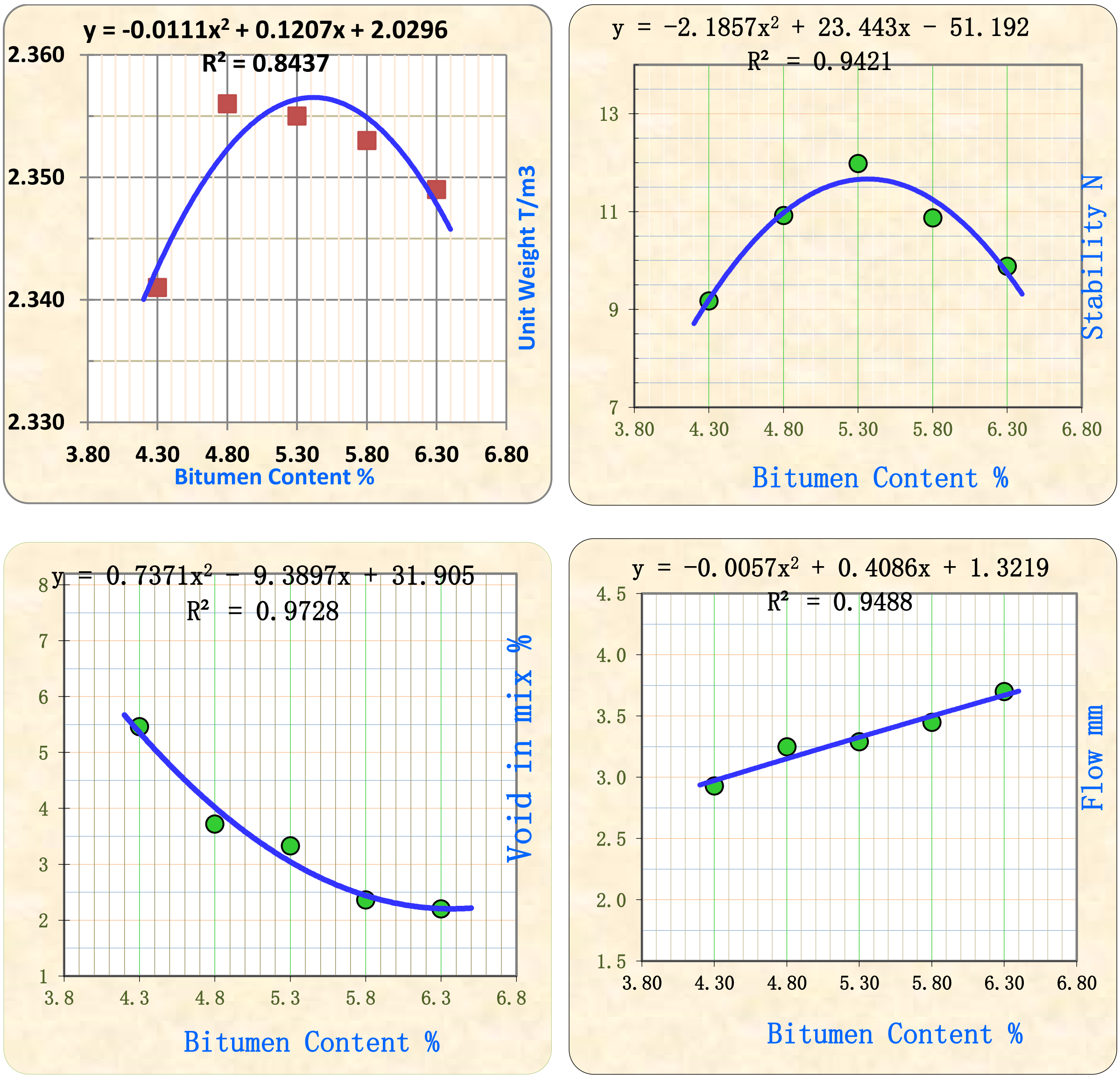
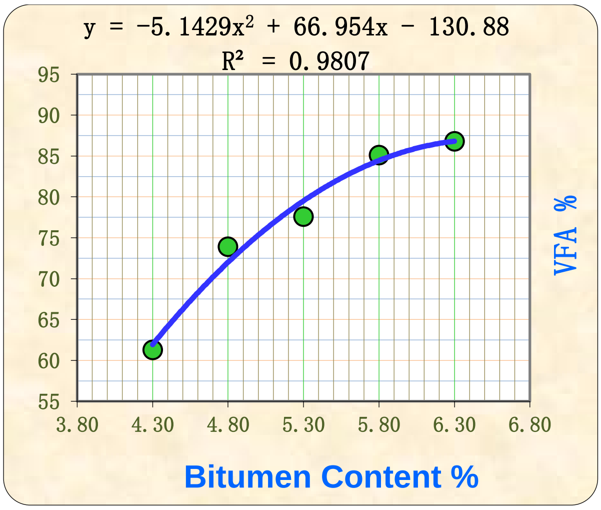


Figure 4.1 Common range of bitumen content at 4.5% CSD

As figure 4.1 shows common range are confirmed the bitumen content giving 4 percent VIM is acceptable, all mix properties of 4.5% filler have compliance with asphalt institute method (MS-2) mix design criteria. Based on this the design bitumen content are 4.7% would minimize the risk of plastic deformation as compared with bitumen content by NAPA method means at 4% VIM and the aggregate particle size distribution should be adjusted further away from the maximum density line to give slightly more VMA





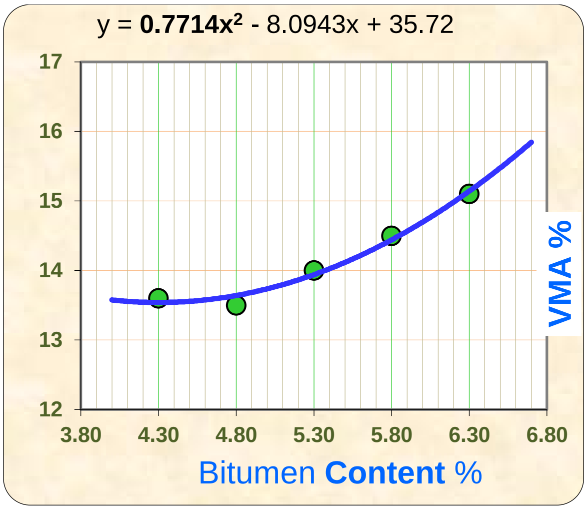


Figure 4.2 OBC and the Marshall properties of HMA mixtures at4.5% CSD filler

Figure 4.2 shows relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA, stability, and Flow by Marshall Method. From this figure, air void is decreasing with increased bitumen content, the value of stability and the unit weight the total mix (bulk density) increases with increasing bitumen content up to pick a point and then gradually decrease although the increase in bitumen content. The value of voids filled with asphalt (VFA), voids in mineral aggregate (VMA) and flow increases with an increase of bitumen content

Table 4.6 Marshall Properties of asphalt mixes conducted for OBC determination at 5.5% CSD

Bitumen content (%)	Bulk SG (Gsb)(Kg/m3)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4%	2.335	5.511	13.800	60.066	10.037	2.870
4.50%	2.342	4.092	14.000	70.771	11.350	3.080
5%	2.349	3.375	14.200	76.235	12.523	3.270
5.50%	2.350	2.284	14.600	84.359	11.333	3.430
6%	2.352	1.868	15.000	87.547	9.860	3.680

According to the chosen method which was MS-2 mix design method, it was specified as figure 4.3 this Common Ranges of mixture at 5.5% conventional filler (CSD) is 4.5 ~ 5.2% bitumen content, Hence Optimum Asphalt Content at 5.5% filler is 4.85%

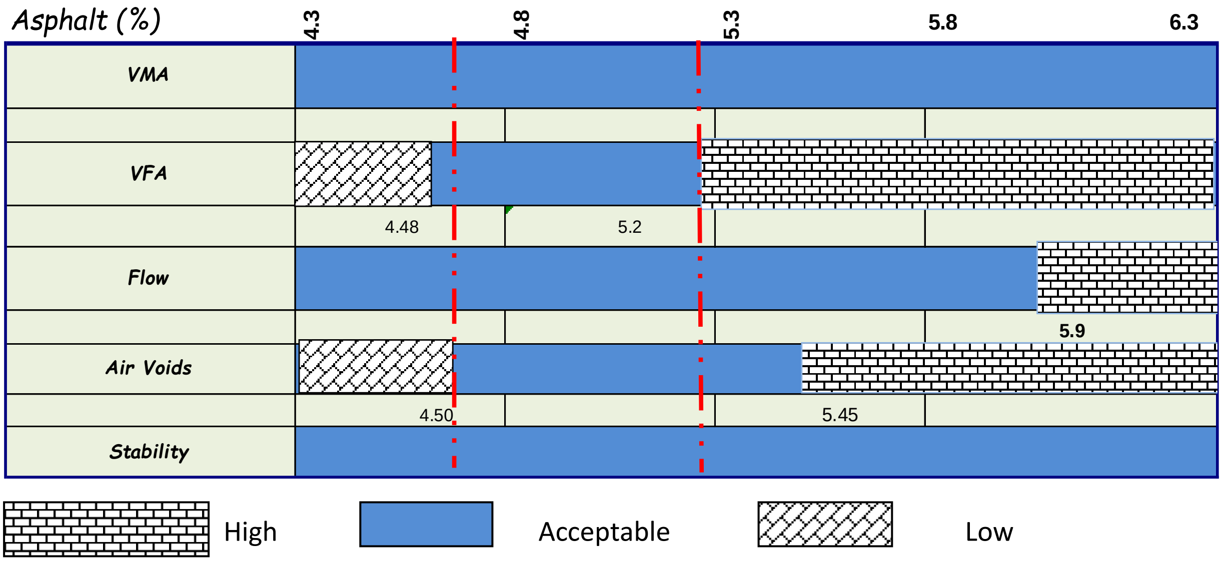
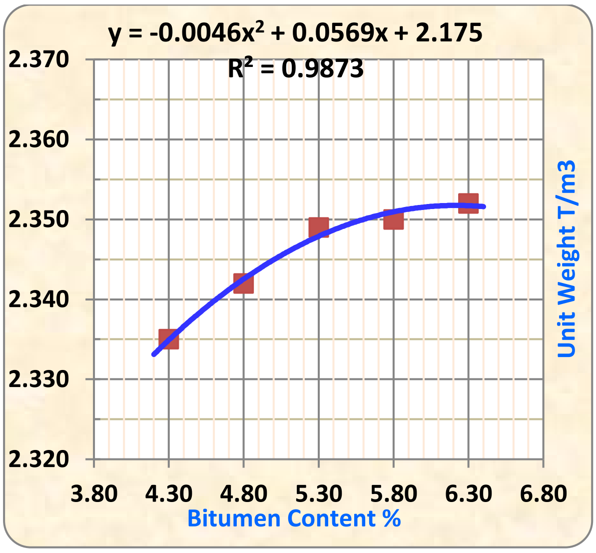
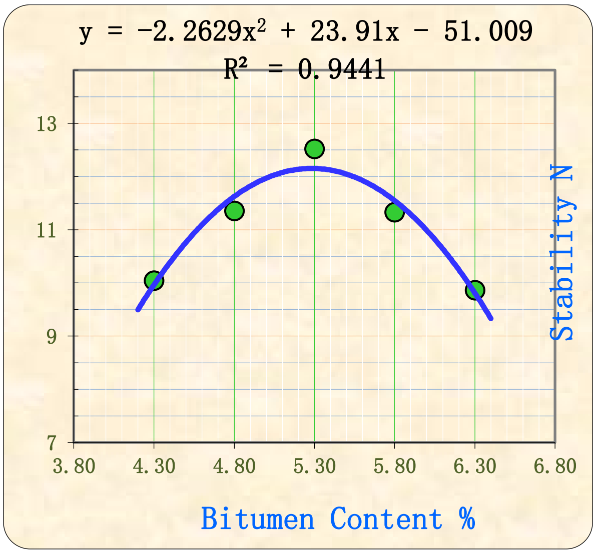


Figure 4.3 Common range of bitumen content at 5.5% CSD

As figure 4.3 shows common range are confirmed the bitumen content giving 4 percent VIM is acceptable, the design bitumen content are 4.85% would minimize the risk of plastic deformation as compared with bitumen content by NAPA method means at 4% VIM and the aggregate particle size distribution should be adjusted further away from the maximum density line to give slightly more VMA





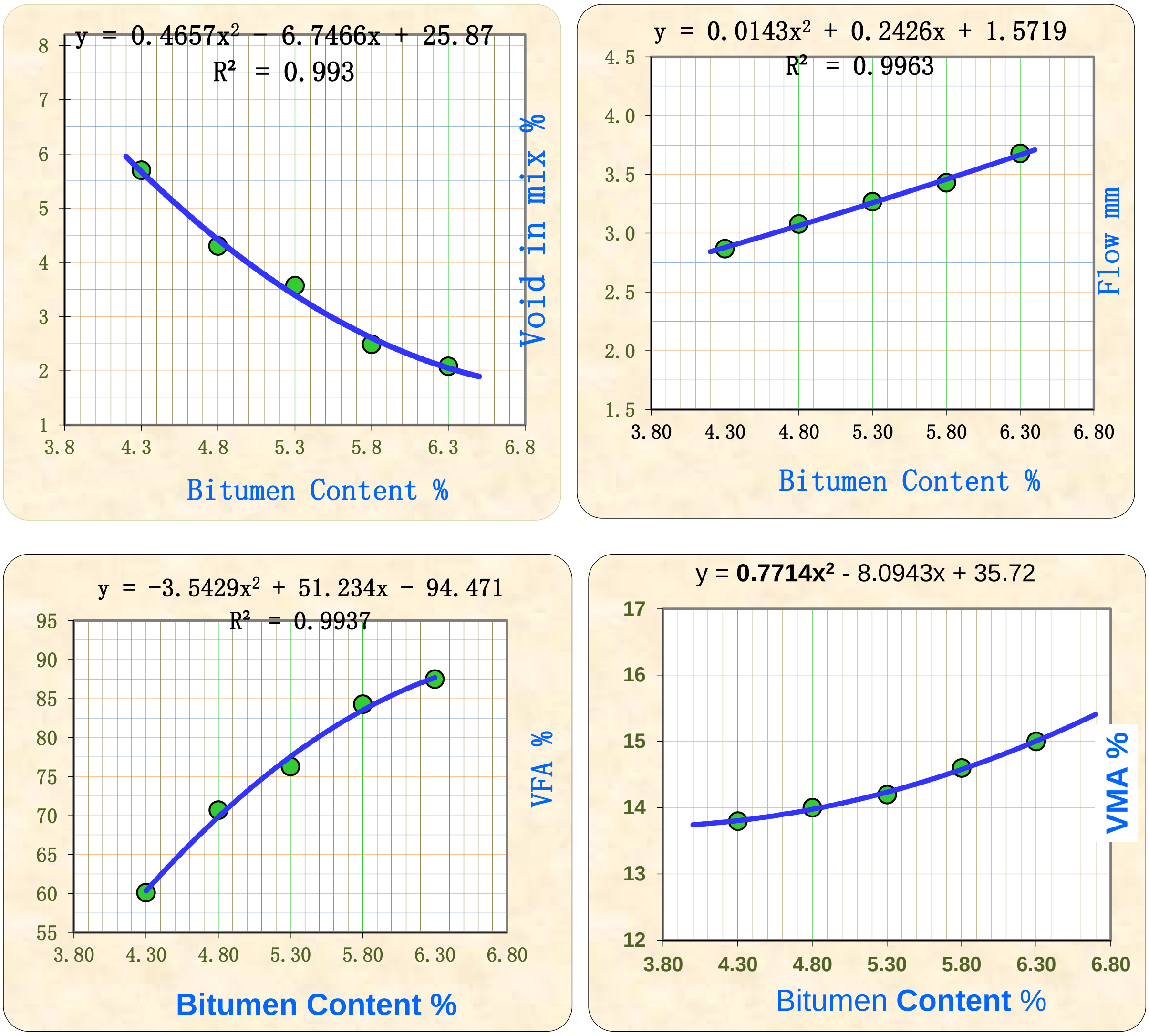


Figure 4.4 OBC and the Marshall properties of HMA mixtures at 5.5% CSD filler

Figure 4.4 shows relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA, stability, and Flow by Marshall Method. From this figure, air void is decreasing with increased bitumen content, the value of stability and the unit weight the total mix (bulk density) increases with increasing bitumen content up to pick a point and then gradually decrease although the increase in bitumen content. The value of voids filled with asphalt (VFA), voids in mineral aggregate (VMA) and flow increases with an increase of bitumen content

Table 4.7 Marshall Properties of asphalt mixes conducted for OBC determination at 6.5% CSD

Bitumen content (%)	Bulk SG (Gsb)(Kg/m3)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.00%	2.317	6.224	14.500	57.078	9.487	2.940
4.50%	2.328	4.658	14.500	67.879	10.770	3.260
5.00%	2.334	3.979	14.700	72.934	11.807	3.430
5.50%	2.346	2.469	14.700	83.203	10.680	3.590
6.00%	2.355	1.753	14.900	88.233	9.807	3.700

According to the chosen method which was MS-2 mix design method, it was specified as figure 4.5 this Common Ranges of mixture at 6.5% conventional filler (CSD) is 4.83 ~ 5.3% bitumen content, Hence Optimum Asphalt Content at 6.5% filler is 5.065%

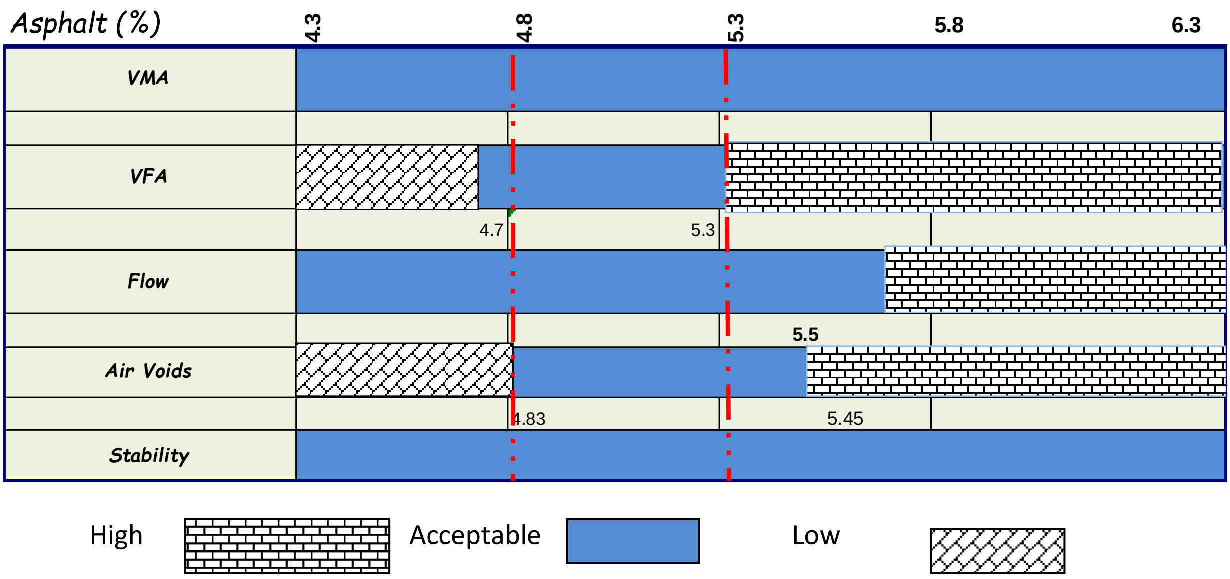


Figure 4.5 Common range of bitumen content at 6.5% CSD

As figure 4.5 shows common range are confirmed the bitumen content giving 4 percent VIM is acceptable, the design bitumen content are 5.065% would minimize the risk of plastic deformation as compared with bitumen content by NAPA method means at 4% VIM and the aggregate particle size distribution should be adjusted further away from the maximum density line to give slightly more VMA

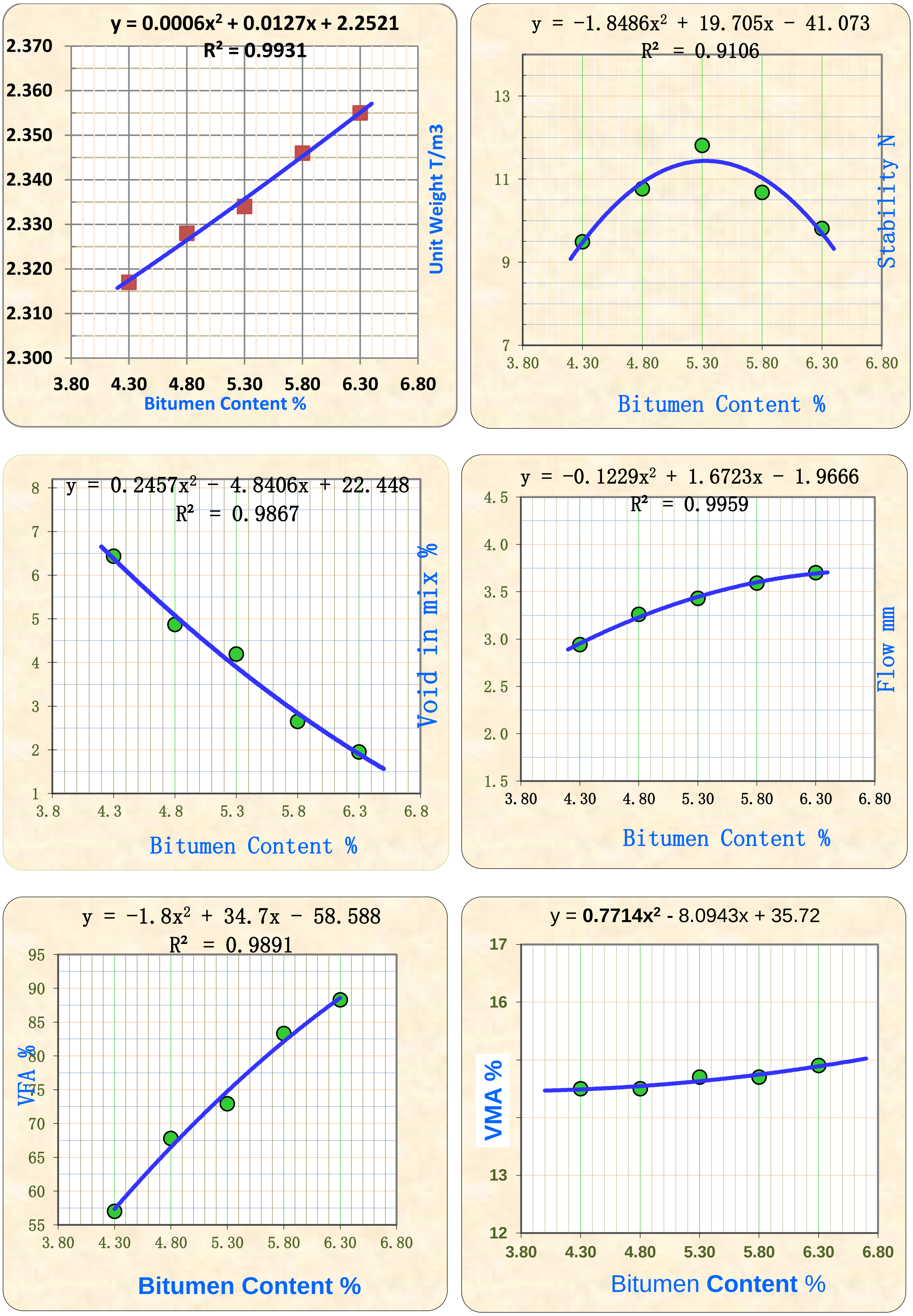


Figure 4.6 OBC and the Marshall properties of HMA mixtures at 6.5% CSD filler

Figure 4.6 shows relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA, stability, and Flow by Marshall Method. From this figure, air void is decreasing with increased bitumen content, the value of stability) increases with increasing bitumen content up to pick a point and then gradually decrease although the increase in bitumen content. unit weight the total mix (bulk density) increased with bitumen content increased. The value of voids filled with asphalt (VFA), voids in mineral aggregate (VMA) and flow increases with an increase of bitumen content

Table 4.8 Marshall Properties of mix design summaries at 4.7, 4.85 and 5.07% of OBC

Properties of mix	% of CSD Filler content			Specifications	
	4.5%	5.5%	6.5%	ERA spec.	Asphalt Inst.
Bitumen, %	4.7	4.85	5.07	4-10 %	4-10%
Air void, %	4.25	4.2	4.5	3-5%	3-5 %
VMA, %	13.7	14	14.5	Min 13	Min 13
VFB, %	72	72.5	70	65-75%	65-75%
Stability, KN	10.75	11.55	11.25	Min 7 KN	Min 8 KN
Flow, mm	3.25	3.21	3.4	2-4 mm	2-3.5 mm
Bulk density, gm/cc	2.352	2.343	2.331	-	-

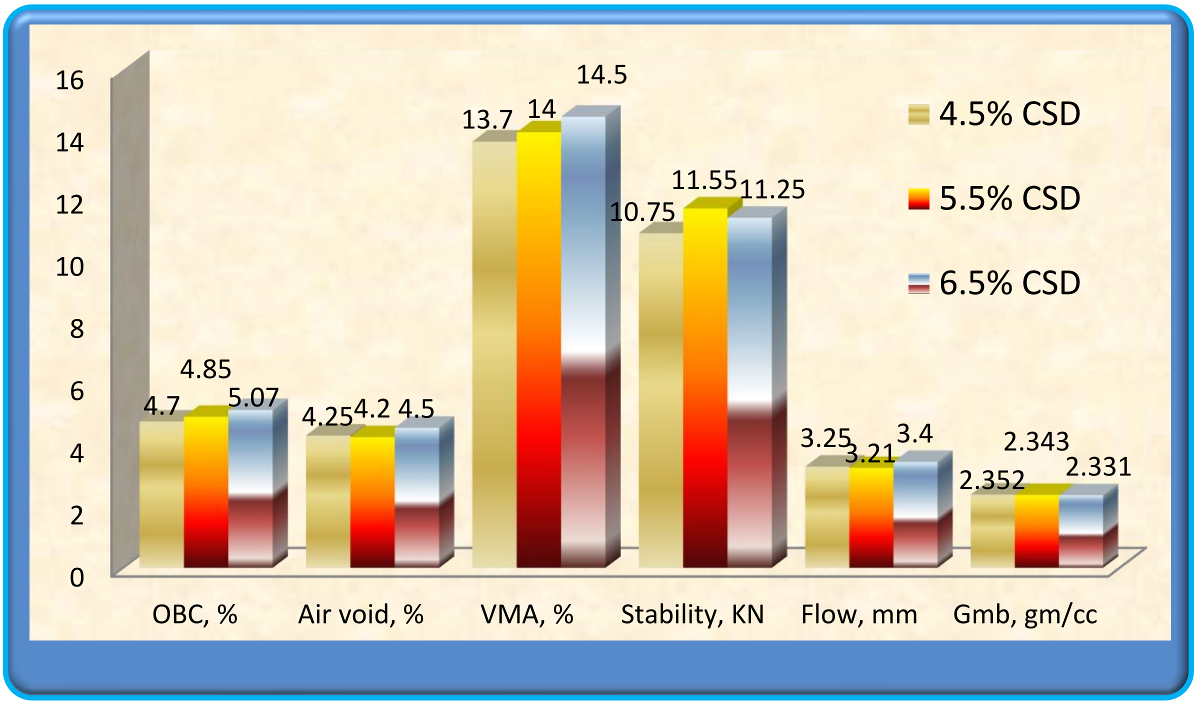


Figure 4.7 Comparison of Marshall Parameters for the three varies of filler content

Table 4.8 indicates the values of Marshall Properties obtained from the plotted bitumen content versus each Marshall Parameter. It was done following OBC determination as in Figures 4.2, 4.4 and 4.6. It shows the result summaries of Marshall Tests and density -void analysis of the three design gradation with its corresponding filler contents (4.5, 5.5 and 6.5%). Figure 4.7 indicates that OBC decreased from 5.07 to 4.7% as filler increase from 4.5 to 6.5%. This resulted from the fact that the void space between the aggregates filled by mineral fillers. And it signifies that there is small room for the binder to occupy. In this case, despite an increment in filler contents literally needs more binder, the available space for incoming binder is already occupied by an increased surface area of fillers which again results in dryness of the mixture. Stability increased from 10.75 to 11.55 kN and then decreased to 11.25 kN as filler contents increase from 4.5 to 6.5%. This was due to uniformly coat the aggregate particles. Such type of mixture may have high stability and low flow which is brittle mix design. In similar VFA increased from 13.7 to 14.5%, as filler contents increased from 4.5 to 6.5%. This is due to the decreased in space available to accommodate the asphalt binder with an increased in amount of fillers. This is resulted from the fact that the higher the density of the mixture leads to the lower the percentage of voids in the mix. It occurred as a result of the decreased in VMA of the mixtures. Therefore despite all parameters corresponding to the three fillers (4.5, 5.5 and 6.5%) met the standard requirements, the 5.5% CSD with its respective 4.85% of OBC and

5.5% filler gradation was selected as the best fit, based on maximum Marshall Stability so that 5.5% OFC and 4.85% OBC were used for replacement mix design of this study

4.3 Replacement of CSD with WMD

Based on the selected optimum bitumen content (4.85%) and optimum filler content (5.5%), CSD was substituted with different percentages of non-conventional filler (WMD) which are six different replacement rate (0, 20, 40, 60, 80 and 100%) by the mass of total filler content on Marshall stability, flow, air void, void in mineral aggregate, void filled with bitumen were determined and compared with control mix as well as with specification. Different filler content and mixture proportions were given in table 4.9

WMD content (%)	Bulk SG (Gsb)(Kg/m3)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
0%	2.322	4.850	14.500	66.549	13.10	2.81
20%	2.320	4.309	14.600	70.490	10.62	3.28
40%	2.337	4.235	13.900	69.530	11.20	3.00
60%	2.355	4.100	13.200	68.940	11.84	3.13
80%	2.357	3.510	13.200	73.410	12.13	2.94
100%	2.359	3.691	14.500	74.546	13.17	2.93

Table 4.9 Marshall Properties of asphalt mixes with WMD at constant bitumen content

4.3.1 Suitability of partial replacement of WMD on Marshal Stability

Stability is the measure of resistance to deformation which influenced by inter-particle frictions of aggregates and cohesions. This friction in turns depends on the different properties of aggregates like surface texture, shape, absorption and structure of aggregates. The cohesion in turns depends on bonding ability of the bitumen that affected by bitumen grade due to variation in viscosity. The effect of WMD on the stability is shown in Figure 4.8 below. The figure illustrate that all test results of stability with different proportion of both conventional and non-conventional filler content has satisfied the specification requirement. Marshal Stability decreases at 20% of replacement and starts increasing at 40% up to 100% of WMD replacement. Based on the result replacement of CSD by WMD has positive impact at up to 100%. Although, all meet the requirement as per ERA specifications, generally the replacement of WMD up to 100% has significant effect on mixture.

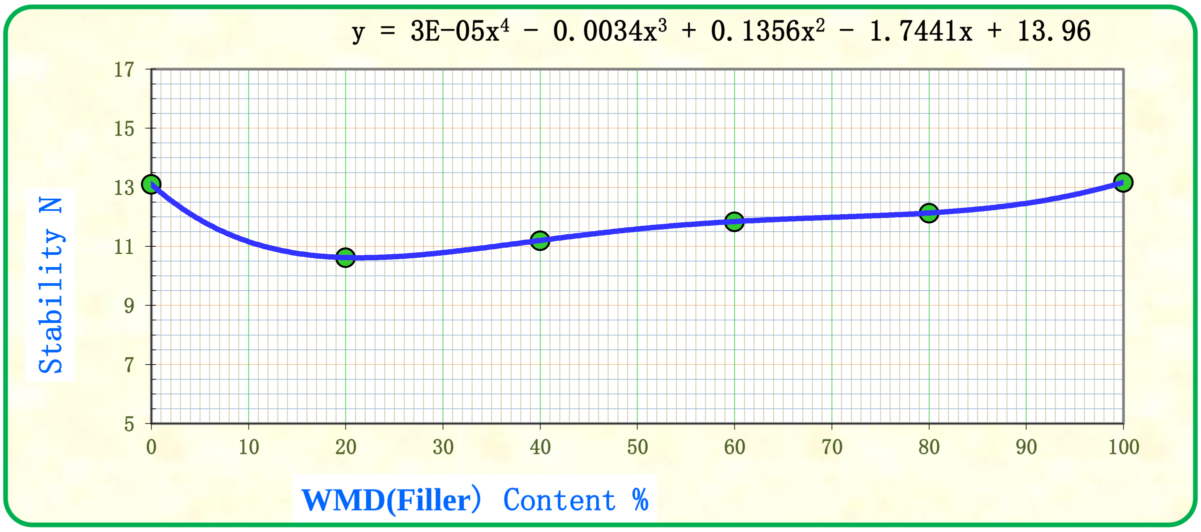


Figure 4.8 Relationship of partial replacement CSD with different percentage of WMD and Stability

4.3.2 Suitability of partial replacement of WMD on Flow

Flow is the measure of elastic and plastic (deformation) and change in shape of mixture due to a load to the boundary of failure. It is measured from start of loading to the decline of stability. The Marshall flow is the vertical deformation of the specimen at the failure point. As it is clearly shown in Figure 4.9 below, the Marshal Flow values obtained from the laboratory prepared mixes using all of WMD percentage, meet the Marshal criteria (2.0mm – 3.5mm). For mixes prepared using 20%, 40%, 60%, 80% and 100% of WMD replacement rate, the flow values obtained are relatively the same. All replacemen are meet the requirement as per as ERA specifications.

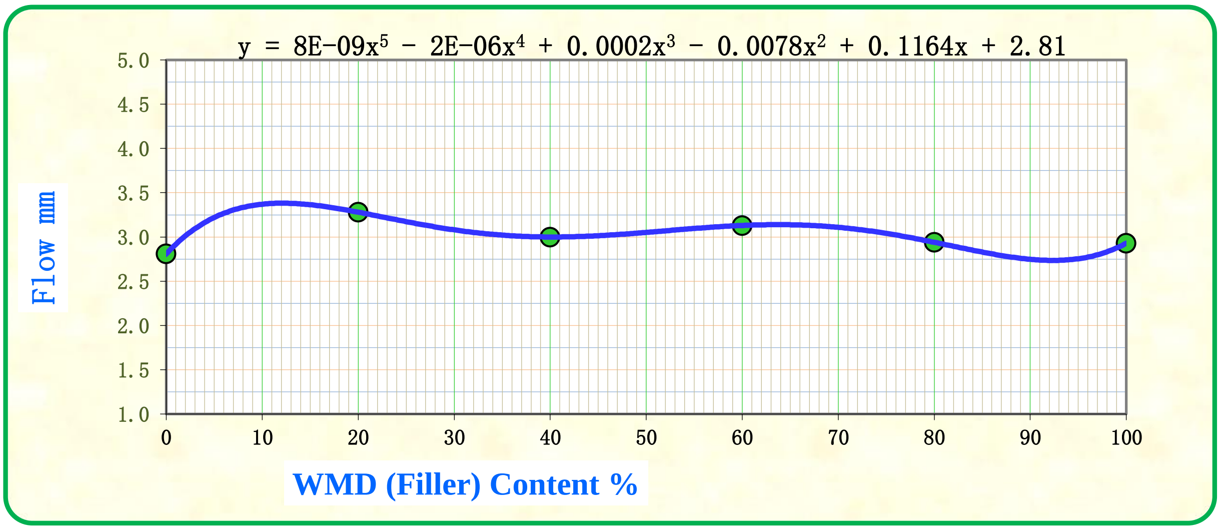


Figure 4.9 Relationship of partial replacement CSD with different percentage of WMD and Flow

4.3.3 Suitability of partial replacement of WMD on Air Void of the mix

The voids in total mix refer to the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. Based on the figures 4.10 below each mixes don't follow a general pattern. According to the test results, all HMA mixtures prepared with partially replacement by WMD filler provided the air void content within the range of 3% - 5% specified by ERA, pavement design manual, as well as Asphalt institute specification. Figure 4.10 shows that at 100% WMD filler content, the air void percentage was 3.69%. Therefore the replacement at 100% provides better result when compared with the other mix percentages

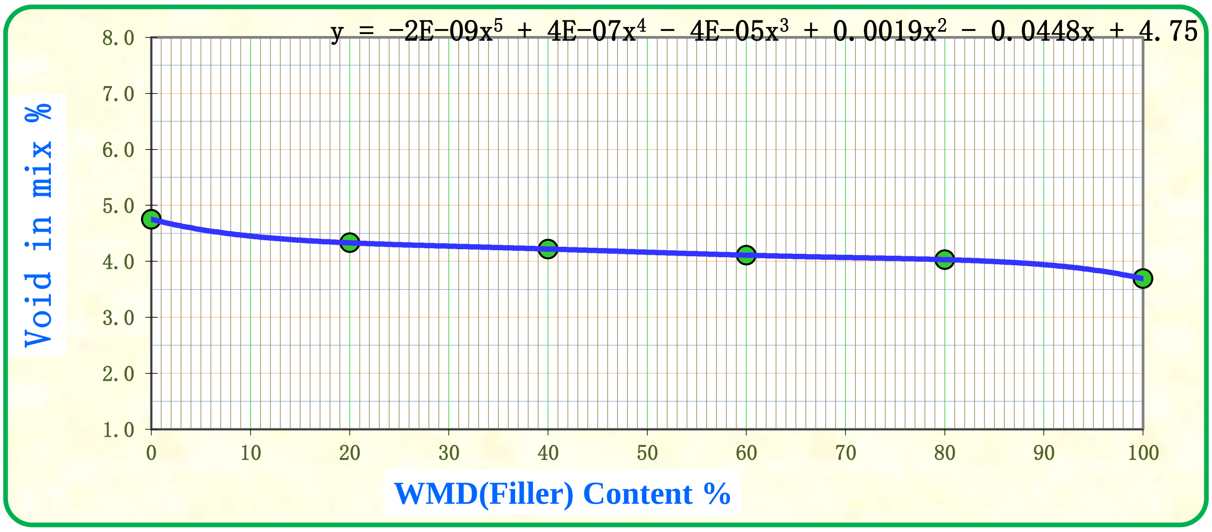


Figure 4.10 Relationship of partial replacement CSD with different percentage of WMD and Void in mix

4.3.4 Suitability of partial replacement of WMD on Void filled with Asphalt

The void in asphalt concrete mix is highly influenced by the nature of aggregates and filler used in the mixture. void filled with asphalt is measured as the proportion of VMAs that are occupied with asphalt binder. Suitability of different replacement percentage of WMD on the voids filled with bitumen property of the mixture is indicated on Figure 4.11. All the mixes of replacement follow a general trend that with an increasing replacement rate of MWD the VFA in the total mix increases. According to the experimental results, VFA values increase with an increase replacement rate of WMD filler until it reaches 100% replacement rate. According to ERA pavement design, manual VFA values in hot mix asphalt mixtures are within a range of 65% - 75%. Thus, as illustrated on figure 4.11, all mixture with WMD combined gradation are satisfied the requirement

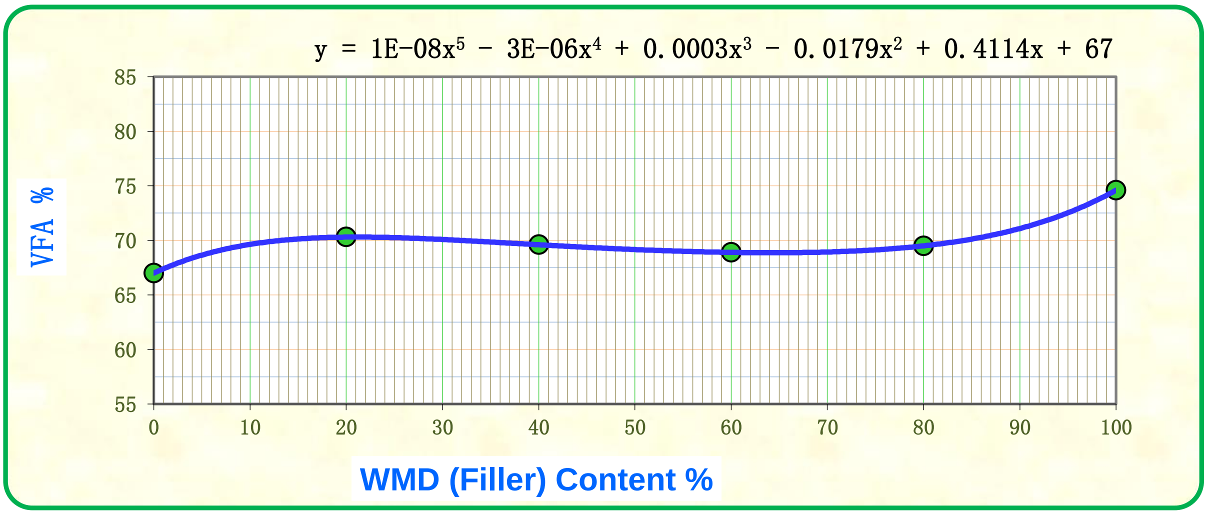


Figure 4.11 Relationship of partial replacement CSD with different percentage of WMD and VFB

4.3.5 Suitability of partial replacement of WMD on Void in Mineral Aggregate

The Void in mineral aggregate is the volume of inter granular void space between the aggregate particles of a compacted paving mixture. The suitability of different percentage of WMD filler on the VMA of the bituminous paving mixture is demonstrated in figure 4.12. The general pattern of the figure is as replacement rate of WMD increases the VMA of the paving mixture increases then decrease. Based on the laboratory results, though it is indicated that the VMA of all hot mix asphalt mixtures is within the allowable limits specified in the ERA pavement design manual. According to ERA pavement design, a manual VMA value in hot mix asphalt mixtures has to be greater than 13%. Thus, as illustrated on figure 4.12, all mixture with WMD are satisfied the requirement.

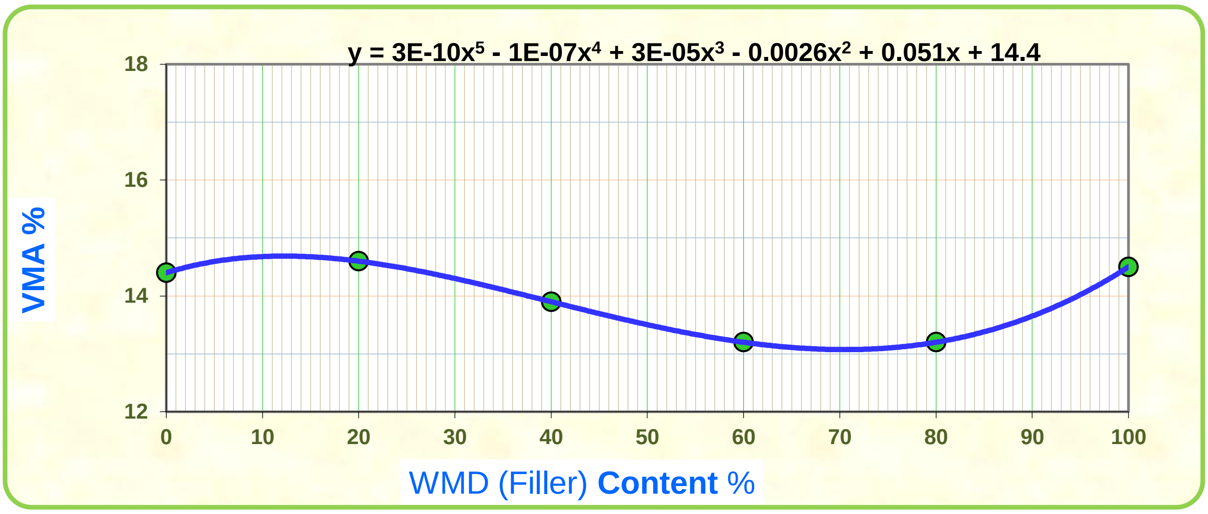


Figure 4.12 Relationship of partial replacement CSD with different percentage of WMD and VMA

4.3.6 Suitability of partial replacement of WMD on Bulk Density

The unit weight of each mixes with different replacement rate of WMD is within the range of requirement. Figure 4.13 shows the bulk density increase with an increase of WMD until it reaches 80% of WMD filler content. Then, the bulk density starts decreasing as the replacement rate increases. Based on the investigation results the replacement rate of 100% of WMD provides greater bulk density when compared with other replacement rate.

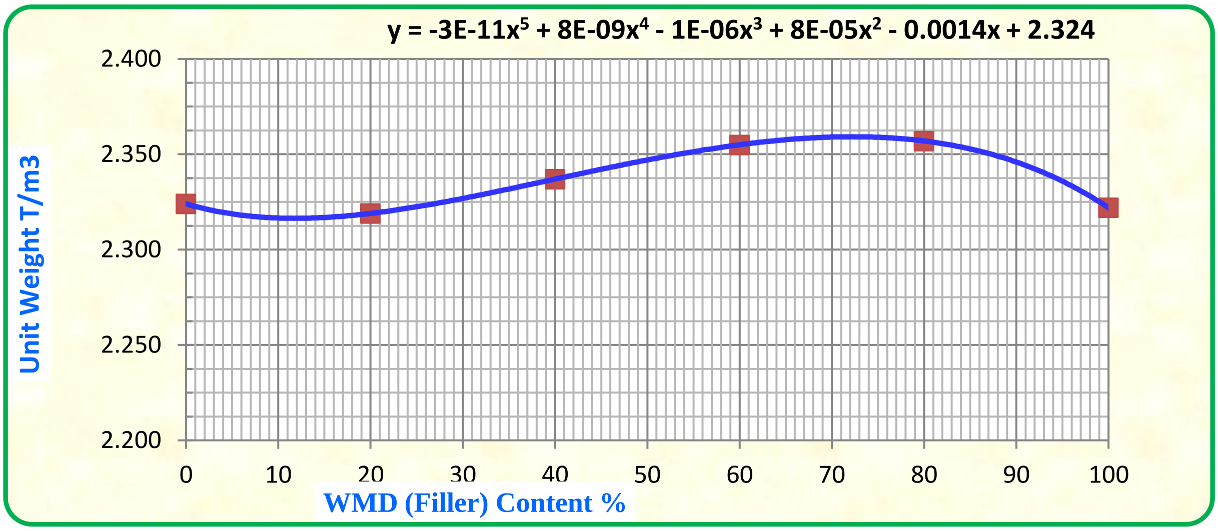


Figure 4.13 Relationship of partial replacement CSD with different percentage of WMD and Unit weight

4.4 Replacement of CSD with CR

Based on the selected optimum bitumen content (4.85%) and optimum filler content (5.5%), CSD was substituted with different percentages of non-conventional filler (CR) which are six different replacement rate (0, 5, 10, 15, 20 and 25%) by the mass of total filler content on Marshall stability, flow, air void, void in mineral aggregate, void filled with bitumen were determined and compared with control mix as well as with specification. Different filler content and mixture proportions were given in table 4.10

Table 4.10 Marshall Properties of asphalt mixes with CR at constant bitumen content

CR content (%)	Bulk SG (Gsb)(Kg/m3)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
0%	2.322	4.850	14.500	66.549	13.10	2.81
5%	2.326	4.030	14.300	71.817	11.88	3.25
10%	2.344	3.922	13.700	71.371	12.23	2.81
15%	2.366	3.682	12.800	71.234	12.89	2.79
20%	2.357	3.508	13.200	73.424	10.99	3.09
25%	2.311	4.162	14.900	72.070	10.05	3.65

4.4.1 Suitability of CR on air void of HMA

As Figure 4.14 indicates, the VA in CSD-CR mix is decreased from up to 15% then after 15% start to increase as increased percent of replacements. It occurred as a result of difference in effective binder and surface area of CR in the mixtures. The decreased in VA of CSD-CR mix arise from an increased in effective binder that coated the mixture uniformly. In another way, the increased in VA in case of CSD-CR mixture is due to the decreased in effective binder resulted from the lost binder film. And also the variation of the VA is due to the difference in percent of replacements of the mixtures.

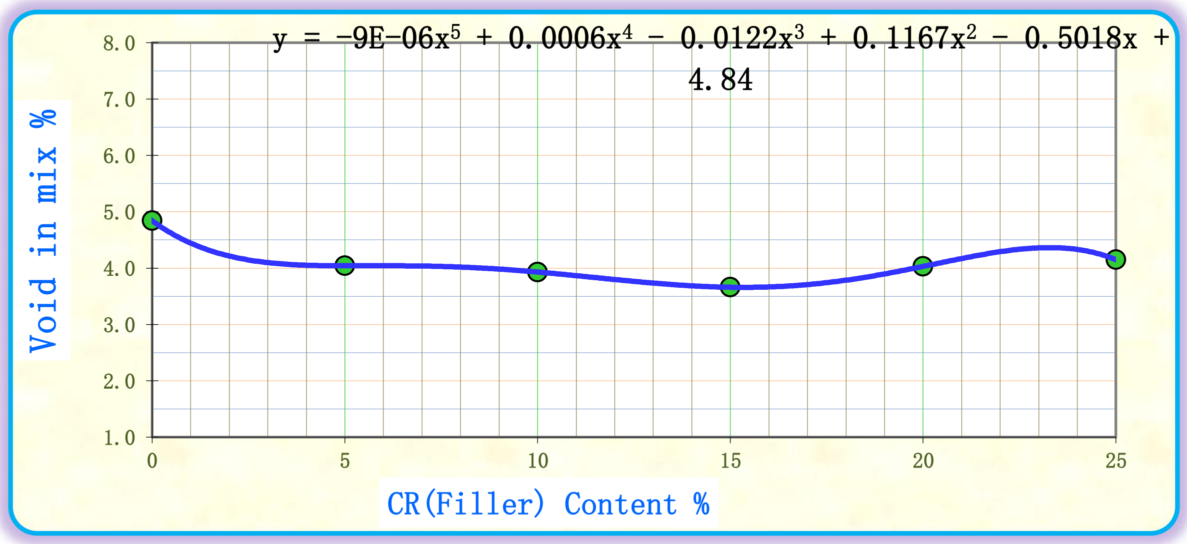


Figure 4.14 Relationship of partial replacement CSD with different percentage of CR and Void in mix

4.4.2 Suitability of CR on bulk specific gravity of HMA

Figure 4.15 shows that the bulk specific gravity of compacted specimens of CSD-CR asphalt mix is increased until 15% then after 15% start to decreased as percent of replacement rises from 0 to 25%. Since density is depend on closeness packing of materials, the greater density of the compacted specimen is the less in void content with higher in effective binder. Thus, the decreased in Gmb of the compacted specimens in CSD-CR mix is due to an increase in voids (VMA).The increased in void resulted from the lost in effective binder that absorbed into internal surface of the mixtures as percent of replacement rises.

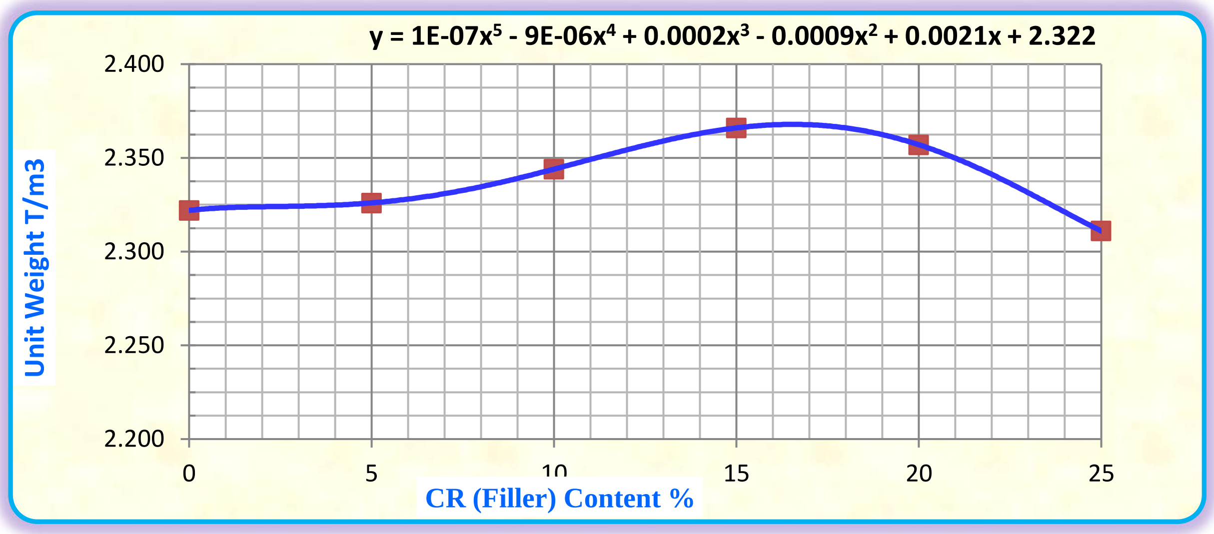


Figure 4.15 Relationship of partial replacement CSD with different percentage of CR and Unit weight

4.4.3 Suitability of CR on void in mineral aggregate of HMA

In this study, the VMA of CSD-CR mixtures is slightly decreased then start to increase as percent of replacement rises from 0 to 25% as illustrated in Figure 4.16. It occurred due to the difference in mineral composition nature of the fillers that influences the absorption capacity of the filler. The variation in effective binder happen when the portion of binder required to form bonding film on aggregate surface is lost by absorption into aggregate. It occurred due to high in internal porosity (absorption capacity) of the filler. Here, the binder portion lost due to absorption into aggregate surface is the reason for increased in VMA of CSD-CR mix the other factor that may cause the variation in VMA of CSD-CR mixtures is the difference in percent of replacement in the mixtures. This difference can influence the surface area of fillers differently. The variation in surface area at the similar weight also arises from difference in specific gravity of the materials. This variation in surface area of the filler again affects the effective binder since the greater in surface area filler cause for more effective bitumen to be lost and vice versa.

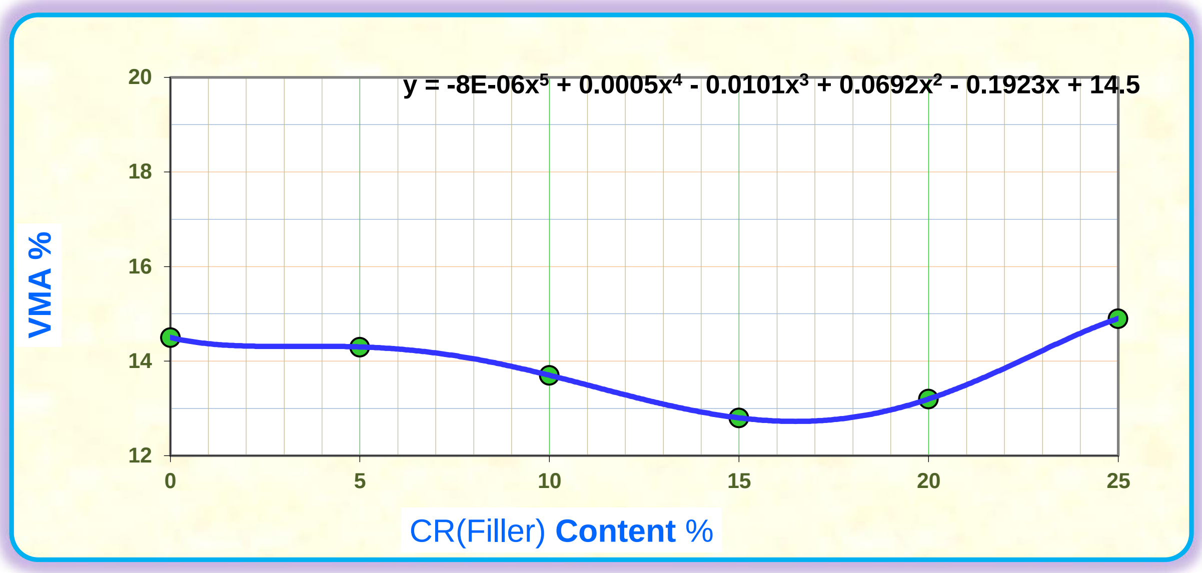


Figure 4.16 Relationship of replacement CSD with different percentage of CR and VMA

4.4.4 Suitability of CR on void filled with asphalt of HMA

Suitability of different replacement percentage of CR on the voids filled with bitumen property of the mixture is indicated on Figure 4.17. All the mixes of replacement follow a general trend that with an increased or decreased according to the experimental results, VFA values decreased with an increase replacement rate of CR filler until it reaches 15% replacement rate. According to ERA pavement design, manual VFA values in hot mix asphalt mixtures are within a range of 65% - 75%. Thus, as illustrated on figure 4.17, all mixture with WMD combined gradation are satisfied the requirement

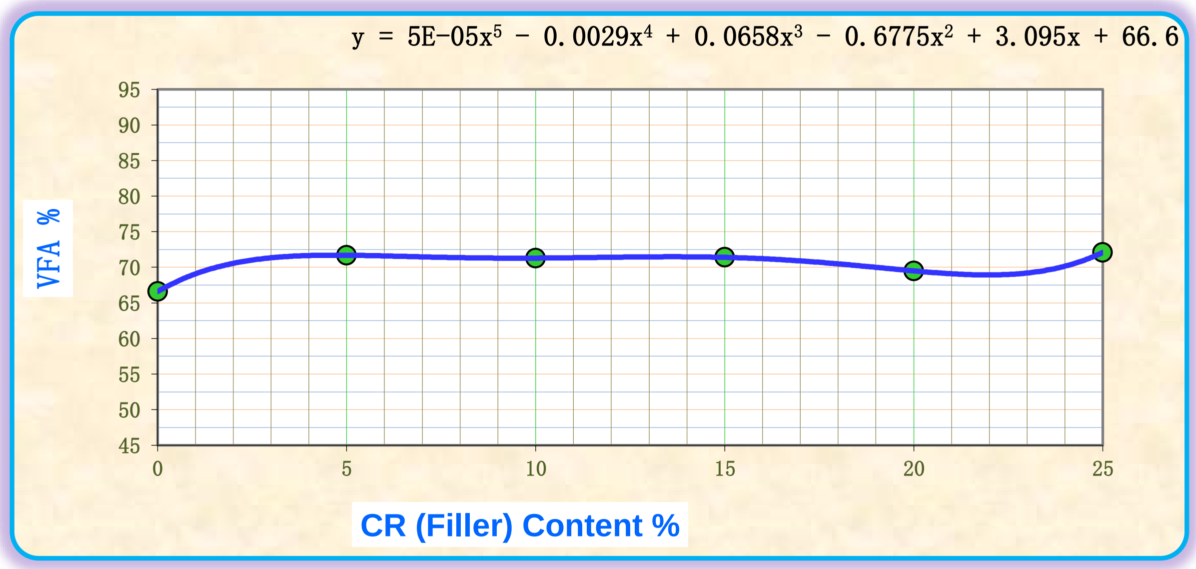


Figure 4.17 Relationship of partial replacement CSD with different percentage of CR and VFA

4.4.5 Suitability of CR on stability of HMA

As indicated in Figure 4.18, the stability of CSD-CR mix specifies an increasing from 11.88 to 12.89 kN as the percent of replacement increased from 5 to 15% then after 15% start to declined. An increase in stability indicates the strong adhesion between aggregates and binder for this mix design while it signifies poor adhesion for the decreased case. This study reveals that it is possible to use CR up to optimum of 15% by weight of CSD

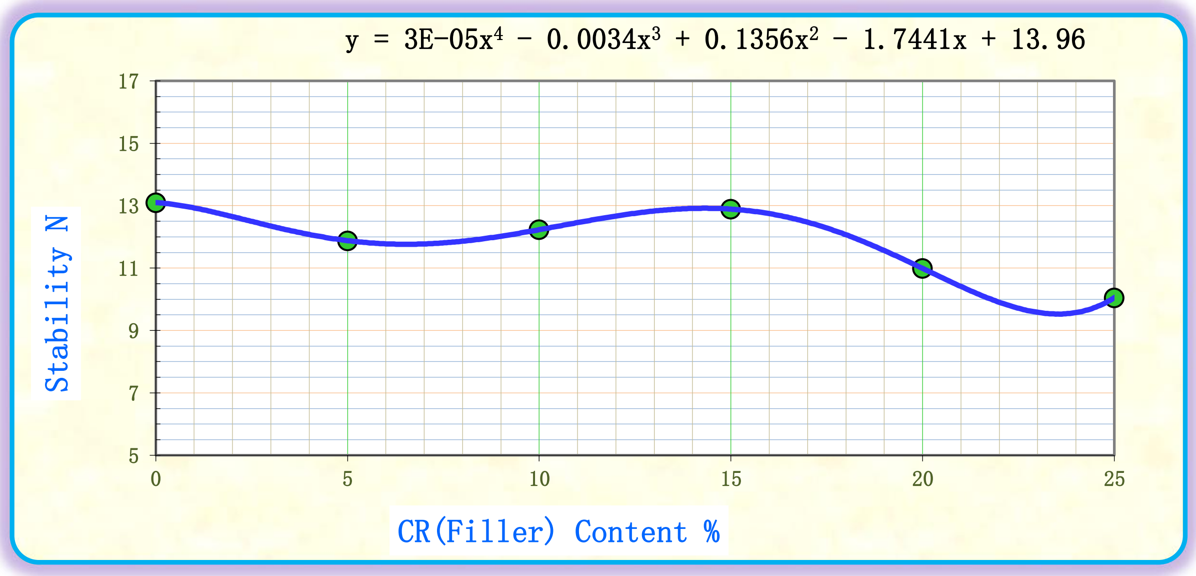


Figure 4.18 Relationship of partial replacement CSD with different percentage of CR and Stability

4.4.6 Suitability of CR on flow of HMA

The Marshall flow is the vertical deformation of the specimen at the failure point. As it is clearly shown in Figure 4.19 below, the Marshal Flow values obtained from the laboratory prepared mixes using all of CR percentage, meet the Marshal criteria (2.0mm – 3.5mm) except for 25% replacement. For mixes prepared using 0, 5, 10, 15, 20 and 25% of CR replacement rate, the flow values obtained are relatively the same. Higher values of flow were also obtained for mixtures prepared using 15% CR replacement rate. At 25% replacement rate the flow doesn't meet the requirement as per as ERA specifications.

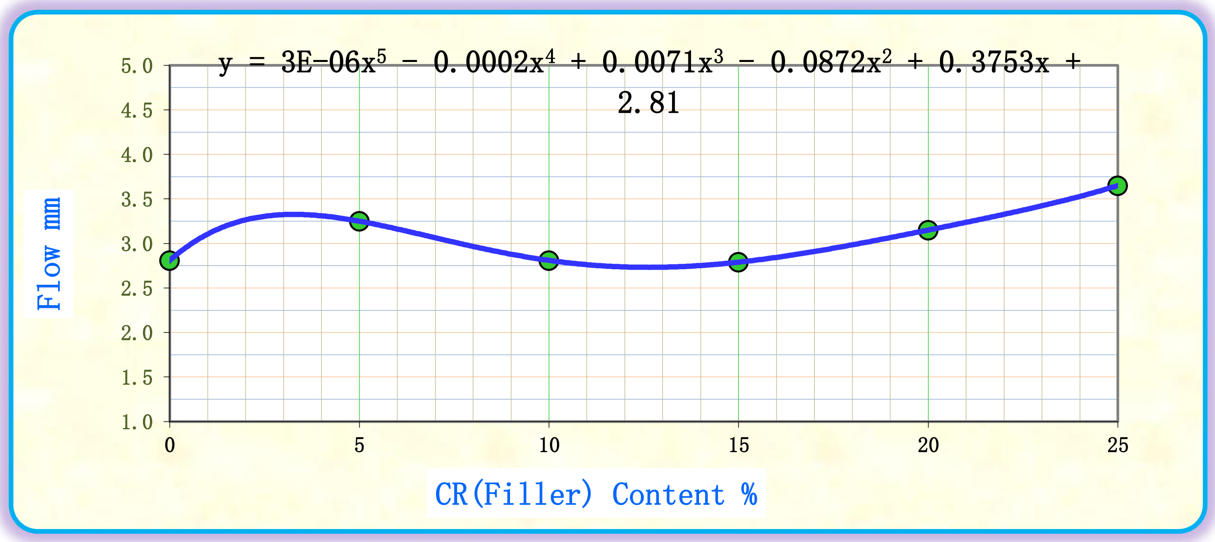


Figure 4.19 Relationship of partial replacement CSD with different percentage of CR and Flow

4.5 Comparison properties of asphalt mix at optimum WMD and CR

The comparison of marshal and volumetric properties of asphalt mix at optimum WMD and CR content (100 and 15% respectively by weight of optimum crushed stone dust filler) with local and international specifications are specified on table 4.11. All Marshall Parameters particularly the values of maximum stability, VA and Gmb at 15% CR and 100% WMD respectively met the standard requirements. Therefore, CR can be used as filler in HMA at 15% by weight of CSD while 100% replacement is possible for WMD as alternative filler material.

Table 4.11 Optimum replacements of CSD with WMD and CR

Marshall parameters	Control (100%)	WMD (100%)	CR (15%)	ERA, 2002)		Asphalt Institute,1996		Remark
				Min.	Max	Min.	Max	
Stability (KN)	13.1	13.17	12.89	8	-	8.006	-	OK
Flow, (mm)	2.81	2.93	2.79	2	3.5	2	3.5	OK
Bulk Density, (gm/cm3)	2.322	2.359	2.366	-	-	-	-	OK
(Va %)	4.85	3.691	3.682	3	5	3	5	OK
VMA	14.5	14.5	13.1	13	-	13	-	OK
VFB	66.549	74.546	71.234	65	75	65	75	OK

Table 4.11 All volumetric properties of asphalt mix of optimum CSD, WMD and CR content with local and international specifications are satisfied

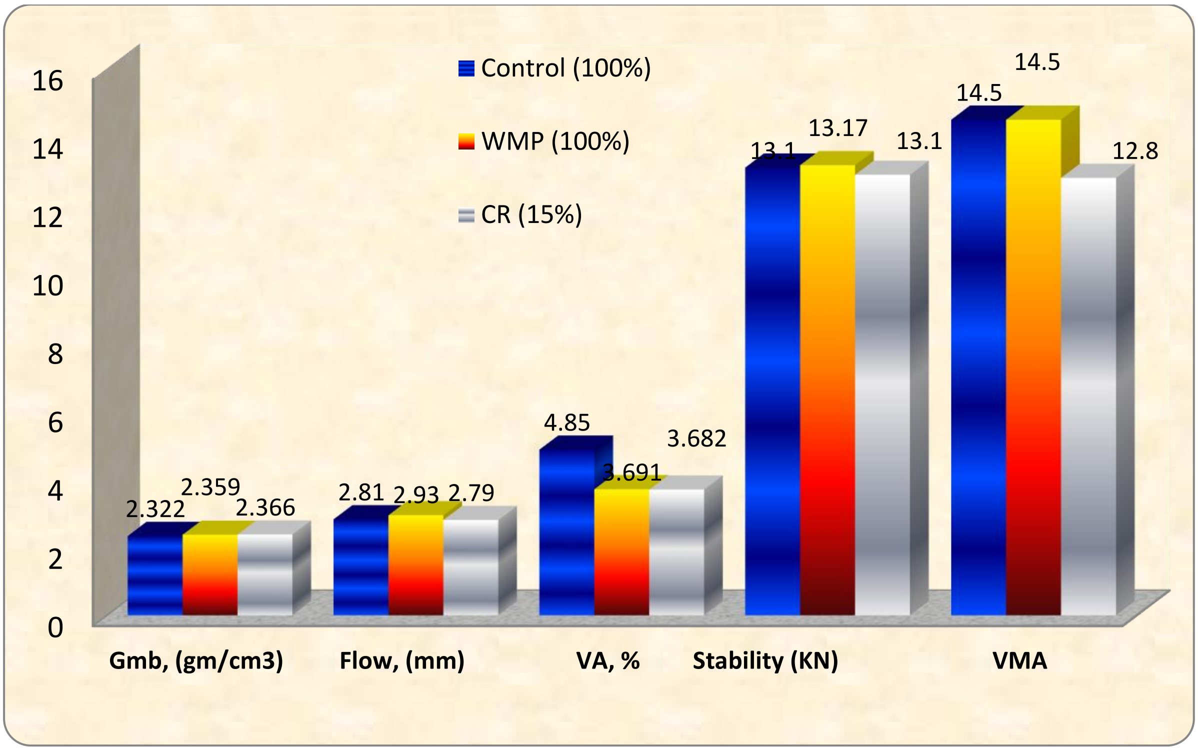


Figure 4.20 comparisons of the marshal properties of asphalt mix containing 100%CSD, 100% WMD and 15% CR

Figure 4.20 illustrates a. The percentage of air voids (VA) of WMD and CR replaced mix was found to be slightly lower than that of normal mix indicates the variation or difference in percent of replacement of two materials. The bulk density of non-conventional of CR at optimum replacement (15%) is slightly higher density than WMD at optimum replacement (100%) replaced mix this indicates that higher bulk density is small void and also low bulk density is higher void. And also the stability of non-conventional replacement WMD at optimum (100%) is slightly higher stability than CSD and CR at optimum (15%), this indicates the higher stabilities have adhesion between aggregate and binders than CR and CSD.

4.6 Effects of WMD and CR on moisture susceptibility

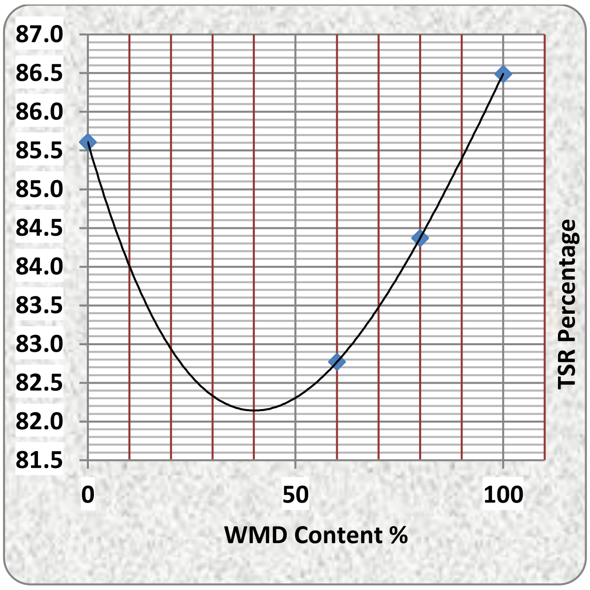
Moisture damage of asphalt mixtures is one of the major distresses in asphalt pavements. The moisture damage is the result of two failure mechanisms, the loss of cohesive bond within asphalt binder and the loss of adhesive bond between the aggregate and the binder

The test results for the tensile strength ratio indicates that the moisture susceptibility of the mix which is the conditional of test group to the control group. The TSR has to satisfy the minimum specification requirement of 80%. TSR values are obtained as a ratio of, (Stm) average tensile strength of the moisture conditioned and (Std) average tensile strength of the dry subset. The mixtures prepared for conventional (control 0%) and non-conventional (CR at the bounder or above and below of its optimum i.e. 10, 15 and 20% and WMD at 100, 80 and 60% were evaluated to indicate the effect of mineral filler types used in the mixes as table 4.12

Table 4.12 TSR for CSD, WMD and CR mixes on moisture sensitivity

Filler type	Filler content	OBC	St2	St1	TSR %
CSD	100% CSD	4.85	725.5	847.7	85.61
WMD	60% WMD + 40% CSD	4.85	722.78	835.99	82.77
	80% WMD + 20% CSD	4.85	709.5	842.3	84.37
	100% WMD	4.85	700.77	846.7	86.49
CR	10% CR + 90% CSD	4.85	719	874	82.25
	15% CR + 85% CSD	4.85	727	864.22	84.12
	20% CR + 80% CSD	4.85	672.9	814.62	82.61

As indicated in Table 4.12, the asphalt mixes prepared with partial replacement at 5.5% by weight of CSD provide the highest TSR values are 85.61%. The values of both CSD-CR and CSD-WMD mixtures are in good performance range, the mix made with CR replacement possesses lower TSR value comparatively. It occurred due to the difference in the physiochemical nature of Crumb rubber. The study reveals that as percent of CR increases at constant 4.85% of OBC, there was slightly increase in dryness of the mixes. This is due to the existence of fewer portions of binder films on aggregate surface as a result of lost in effective binder because of internal absorption of aggregate. And this indicates that the mix prepared with CR require higher OBC than that of WMD to coat the mix uniformly. And this are what pulled down the TSR value of CSD-CR below that of CSD-WMD. Therefore, the relative difference in TSR values of CSD-CR and CSD-WMD mixes is the difference in adhesive bond between aggregate and binder of the two mixtures. As the mix design with greater total void allows more water permeability; the mix with higher absorption capacity is more susceptible to stripping. This is due to the greater in lost effective binder of the mix. For whatever so far, despite of the difference in asphalt film thickness, the TSR values at optimum replacement of the study are in good performance range that are 84.12, 85.61 and 86.49% for CSD-CR, CSD and CSD-WMD, respectively.



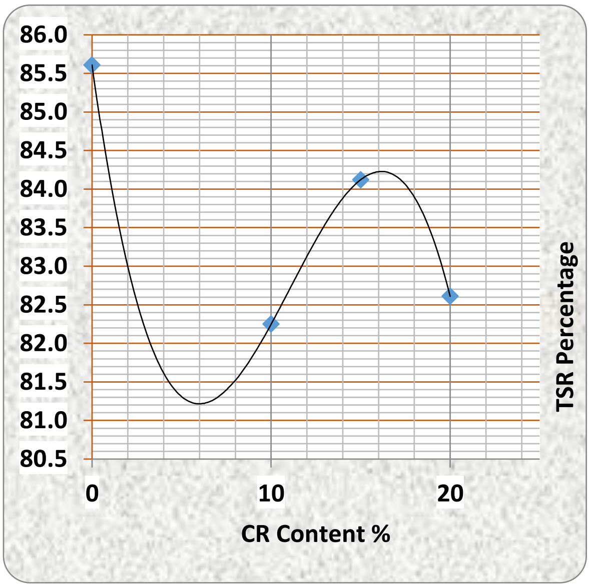


Fig 4.21(a)TSR percentage Vs WMD content% Fig4.21(b) TSR Percentage Vs CR content%

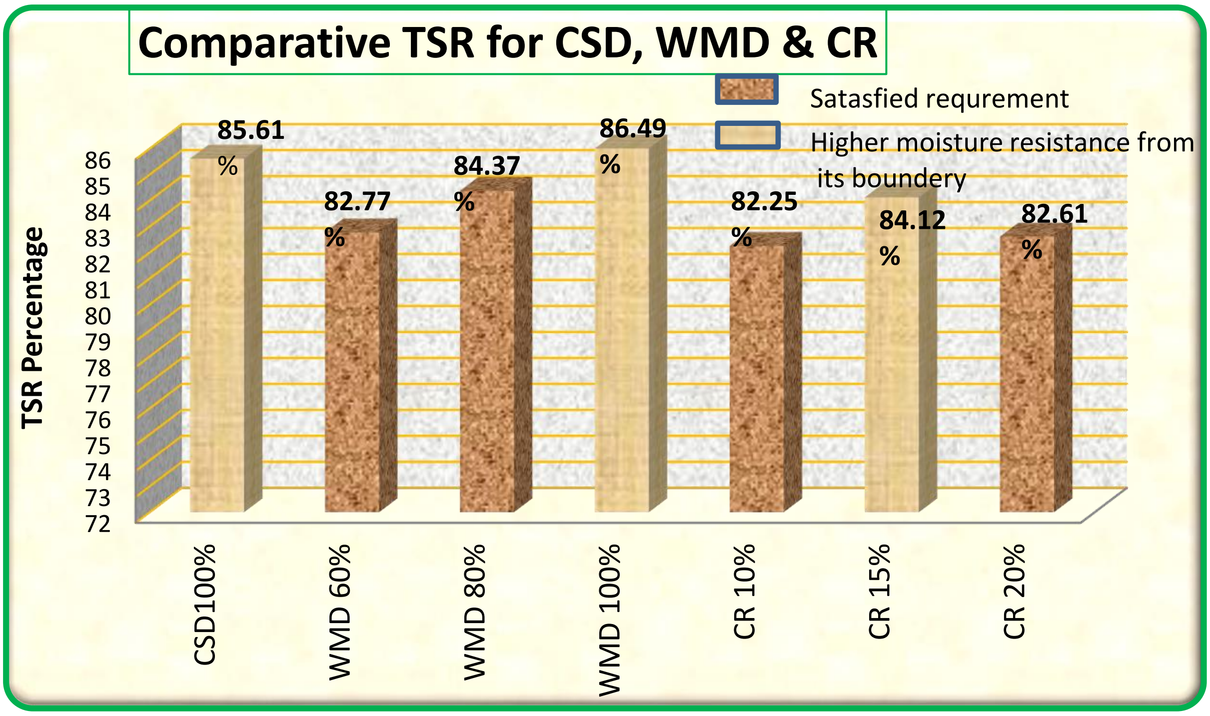


Fig 4.21(c) Comparative of TSR result by using fillers CSD, WMD and CR on asphalt maxis

Figure 4.21 The tensile strength ratio of the asphalt mixture with CSD, WMD and CR

The test results are plotted as shown in Figure 4.21 (a-c) as follows

Figure 4.21 (a) Indicates the asphalt mixture with 100% WMD had a TSR of 86.49%, which fulfilled the specification limit of 80%. And the asphalt mixture with 60 and 80% WMD had a TSR of 82.77 and 84.37% respectively which indicate the Adding WMD to the asphalt mixture increased the TSR values also increased

Figure 4.15(b) Are shows the specimen with 10 and 15% CR are 82.25 and 84.12% TSR values respectively, which are fulfilled the specification limit of the moisture sensitivity test which are 80%. Hence adding CR on the asphalt mixture is increased the TSR values until 15% CR then start to decline this also indicates in this replacement as replacement percent of CR increased up to 15% CR void is decreased then after 15% void is start to increase this indicate. Greater void allows more water permeability that means the mix after 15% CR are higher absorption capacity is more susceptible to stripping. So mix after 15% CR may loss of cohesive bond between aggregate and binder

Figure 4.15(c) Is indicates the comparison between values obtained using different mineral fillers in the mix. As it is noticed that mixes prepared using 100% WMD filler provide highest retained stability as compared to mixes prepared CSD and 15% CR. This indicates that mixes prepared using WMD fillers are better resistance to moisture effects. Followed the mixes prepared CR is lowest moisture resistance as compared with CSD fillers. This due to occurrence of different physical and chemical nature of material that means WMD are higher SO_2 or 52.44% than 15% CR or 47.33% this indicate SO_2 is not soluble in either water or organic solvent due to this WMD are more moisture susceptibility resistance than 15% CR.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Asphalt is a combination of aggregate, filler and bitumen. In order to meet the objective of this study, the characterization of these asphalt components and Marshall Mix design study on suitability and effects of CR and WMD were performed. In addition to this, the asphalt performance test on water susceptibility was conducted. Accordingly, the following conclusions are drawn based on experimental findings:

- Laboratory test of physical properties of aggregates (AIV, ACV, LLA, Flakiness index, Water absorption, Apparent SG, Bulk SSD S.G and Bulk dry S.G), bitumen (Penetration grade, softening point, Ductility, Flash Point and Specific Gravity) and fillers (plastic index and specific gravity) used in the hot mix asphalt results are satisfied minimum requirement specification.
- The chemical properties of WMD and CR statistically result indicated that the MgO composition required for pozzolan was 2.07% and 2.33% respectively which is less than the maximum requirement. The composition of SO_3 found in WMD and CR material to be 1.92 and 2.66% respectively which is less than the 4% of the specified maximum requirement. SiO_2, Al_2O_3 and Fe_2O_3 of both samples is a good pozzolanic materials satisfied minimum requirement specification.
- Marshall Stability, flow values and volumetric properties for filler content (4.5, 5.5 and 6.5%) satisfy with the ERA Pavement Design Manual specification limits.
- The OFC of CSD was determined on the basis of maximum Marshall Stability, maximum unit weight and flow on the range. It was observed that 5.5% filler content of CSD and by using MS-2 method OBC was selected at 4.85% were used for replacement mix design of the study.
- From the optimum test result, the potential of WMD and CR as filler materials in HMA was at 100% of WMD and 15% of CR with 85% of CSD filler contents are satisfying the control specification those are Maximum bulk density, Maximum stability and Va% within the allowed range of specification and Suggested the utilization of full and partial replaced of WMD and CR for HMA.
- The asphalt mixtures with 100%CSD, 100%WMD and 15%CR with 85% of CSD are 85.61, 86.49 and 84.12% of TSR result respectively, so all are fulfilled the TSR

specification. The WMD containing mixture was industrial waste materials had higher TSR, this indicating a higher moisture resistance of HMA when compare with CSD and CR.

- ❖ Therefore, the study shows that CR can be used as filler in HMA at 15% by weight of CSD while 100% replacement is possible for WMD as alternative filler material at 5.5% filler content

5.2 Recommendations

Based on the study results the following recommendations are given:

- ❖ WMD can be used fully or as partial replacement when combined with CSD to realize the best HMA mixture.
- ❖ CR can be utilized as partial replacement at 15% by weight of CSD when combined with CSD to realize the best HMA mixture.
- ❖ Government and local agencies are advised to use Non-Conventional filler (Waste marble dust and crumb rubber) as partial replacement of conventional filler (CSD) in HMA with a maximum percentage of 100% and 15% respectively by weight of optimum CSD filler.

- ➢ This research studied some of the basic physical and chemical properties of CSD, WMD and CR as replacing filler material. However, further studies are required on the following:
  - ▪ Further Studies should be made using controlled burning of the CR at different temperature and holding time
  - ▪ Studies should be made to check the pozzolanic reaction, chemical constituents and skeletal structure of WMD and CR using more advanced methods like Scanning Electron Microscopy (SEM) and Thermal Analysis (TGA) which are rarely available Ethiopia now a day
  - ▪ Using WMD and CR partially replacement as a filer material initiates the other researchers to do their researches on new ideas that were not done previously. The other researchers must have to do blending both materials in different percentages
  - ▪ Another further study is required using different bitumen grades to know the variation may happen due to difference in binder viscosity.
  - ▪ Further research should be carried out to investigate the detail cost effectiveness implication on asphalt construction when compared with standard and using WMD

and CR, the cost quantification for WMD and CR should be the focusing area for upcoming researchers, to clearly understand

REFERENCES

AASHTO,. 1995. Standard Specification for Materials for Aggregate and Soil- Aggregate Sub Base, Base and Surface Courses. USA.

Abukhettala,. 2006. "The Relationship between Marshall Stability, Flow, and Rutting of the New Malaysian Hot-Mix Asphalt Mixture,."

Antiohas, Marasahin, and S. Terzi,. 2005. "Evaluation of Marble Waste Dust in the Mixture of Asphaltic Concrete." Elsevier 21(3):616–20.

Asphalt Institute. 1994. Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, MS-2. Lexington, Kentucky. USA: Asphalt Institute.

Asphalt Institute,. 2008. MS-2 Mix Design Methods for Asphalt Concrete and Other Hot Mix. Vol. Sixth Edition.

Asres,. 2013. "The Effect of Hydrated Lime Additives on Moisture Sensitivity and Overall Performance of Hot Mix Asphalt Mixtures."

ASTM,. 1992. Annual Book of ASTM Standards,American Society for Testing and Materials.

ASTM,. 1998. Annual Book of ASTM Standards,American Society for Testing and Materials.

Aydin. 2013. "The Effect of the Marble Powder Used as Fine Material on the Strength and Durability of Concrete."

Blewett, J., and Woodward. 2000. Some Geotechnical Properties of Waste Glass. Department of Civil and Offshore Engineering,. Edinburgh.

Bouchard, G. P. 2005. Effects of Aggregate Absorption and Crush Percentage on Bituminous Concrete Meininger. Ed,Richard C,Philadelphia. American Society for Testing and Material.

Brennan, M. J., and C. A. Flaherty,. 2002. Highways, Design, Construction and Maintenance of Road Pavements. Butterworth-Heinemann. USA.

Bruce, Chadbourn, Skok Eugene, Jr, and Samantha Spindler Benita. 2007. The Effect of Voids in Mineral Aggregate (VMA) on Hot-Mix Asphalt Pavements. Minnesota Department of Transportation Office of Research Services.

Demirel, B., and Elmaci. 2018. . ". Waste Marble Powder/Dust. Elazig."

DPWH,. 2004. Standard Specification. Vol. 2.

Eisa, S. M., and Youssef. Basiouny,. 2018. "Effect of Using Various Waste Materials as Mineral Filler on the Properties of Asphalt Mix. Innovative Infrastructure Solutions." (3) 27.

Eltaher, A., and M. Ratnasamy,. 2016. "An Overview of the Use of Mineral Fillers in Asphalt Pavements." Australian Journal of Basic and Applied Sciences 10(9).

Eltaher, Ratnasamy, M. 2016. "An Overview of the Use of Mineral Fillers in Asphalt Pavements." AJBAS 279–92.

ERA,. 2002. Ethipians Road Authority Pavement Design Manual for Flexible Pavements. Ethiopia.

ERA Manual,. 2013. ETHIOPIAN ROADS AUTHORITY PAVEMENT DESIGN MANUAL.

Freddy, l. 1996. "In Hot Mix Asphalt Materials Mixture Design and Construction." National Asphalt Pavement Association Research and Foundation 2nd Ed. ed.

Freddy, Prithivs. Kandal, and Ray Brown,. 2009. Hot Mix Asphalt Materials, Mixture Design and Construction.

Grabowski, W., and J. Wilanowicz,. 2008. "The Structure of Mineral Fillers and Their Stiffening Properties in Filler-Bitumen Mastics." 44:793–804.

Hassan Y, Ahme. 2006. "EFFECT OF USING WASTE CEMENT DUST AS A MINERAL FILLER ON THE MECHANICAL PROPERTIES OF HOT MIX ASPHALT." AUCES Vol. 9.

Herna´ndez, and Olivares,. 2009. "Rubber-Modified Hot-Mix Asphalt Pavement by Dry Process." Int. J. Pavement Eng 10 (4):277–88.

Huang, Bird, and O. Heidrich,. 2007. "A Review of the Use of Recycled Solid Waste Materials in Asphalt Pavements," Resources, Conservation and Recycling." 52:58–73.

Hunter, R. N. 2015. The Shell Bitumen Handbook. Vol. 6th ed. Self, A. London: ICE Publishing.

Islam, S., and G. Ransinchung. 2020. "Analyzing the Effect of Waste Jarosite as an Alternative Filler on the Engineering Properties of Asphalt Mixes." Construction and Building Materials.

Jahanian, H., and H. Shafabakhsh. 2017. "Performance Evaluation of Hot Mix Asphalt (HMA) Containing Bitumen Modified with Gilsonite." Construction and Building Materials.

Junaid Ahmed, Banerjee. 2016. "The Effective Ways of Utilization of Rice-Husk-Ash in Hot Mix Asphalt." Journal of Basic and Applied Engineering Research Volume 3(Issue 4).

Justo, C., and A. Veeraragavan,. 2002. "Utilization of Waste Plastic Bags in Bituminous Mix for Improved Performance of Roads." Centre for Transportation Engineering.

Kamil E, Kaloush. 2002. "Simple Performance Test for Permanent Deformation of Asphalt Mixtures."

Kar,b, D. 2012. "A Laboratory Study of Bituminous Mixes Using a Natural Fibre." National Institute of Technology.

Kumar, V. Y. 2016. "Partial Replacement of Cement to Concrete by Marble Dust Powder." International Journal of Modern Trends in Science and Technology 2(5):111–22.

Lowa, S. 2010. Evaluation of Hot Mix Asphalt Moisture Sensitivity Using the Nottingham Asphalt Test Equipment. The Iowa Highway Research Board. Iowa State University.

Maganari, K. 2005. “Evaluation of Blends of High and Low Calcium Fly Ashes for Use as Supplementary Cementing Materials”, Cement & Concrete Composites.” Vol. 27:349–56.

Mashaan, N., and R. Karim,. 2014. “N. S. & M. R., “Waste Tyre Rubber in Asphalt Pavement Modification.” Materials Research Innovations 18:S6-6.

mineralzone. 2017. “[Online]. Available: Http://Www.Mineralzone.Com/Stone/Marble.Htm.”

Mistry, S. 2018. “Experimental Evaluation of Rice Husk Ash and Fly Ash as Alternative Fillers in Hot-Mix Asphalt. Road Mater. Pavement.” 1–12.

Modarres, A., and P. Ayar,. 2016. “Comparing the Mechanical Properties of Cold Recycled Mixture Containing Coal Waste Additive and Ordinary Portland Cement.” International Journal of Pavement Engineering 17:no. 3.

Mohammad, A. 2020. Effect of Nominal Maximum Aggregate Size and Aggregate Gradation on the Surface Frictional Properties of Hot Mix Asphalt Mixtures. onstruction and Building Materials.

Mohanty, M. 2013. “A Study On Use of Waste Polyethylene in Bituminous Paving Mixes.”

MORTH,. 2013. Specification for Road and Bridge Works,. Vol. 5’th Edition.

Murana, and Sani,. 2015. “Evaluating the Strength of & L. No. 4, 704 770044 704 Bagasse Ash as Filler in Hot Mix Asphalt Design.” Nigerian Journal of Technology Vol. 34.

Nathem A, and Saffar,. 2013. “The Effect of Filler Type and Content on Hot Asphalt Concrete Mixtures Properties.” volume 21(Number 6).

NCAT. 2011. “National Center for Asphalt Technology,.”

Patil Akshay, and Anand B,. 2020. “Investigation on the Use of Crumb Rubber and Bagasse Ash in Road Construction.” 1–12.

Qasrawi, and Asi. 2016. “Effect of Bitumen Grade on Hot Asphalt Mixes Properties Prepared Using Recycled Coarse Concrete Aggregate.” 121, 18-24. doi:10.1016.

Ratnasamy, M. E. 2013. “Effect of Mineral Filler Type and Particle Size on Asphalt Filler Mastic Asphalt Laboratory Measured Properties.” Australian Journal of Basic And Applied Science 7(11).

Roberts, E. R. Brown, Dah-Yinn Lee, and Kennedy,. 2006. “Hot Mix Asphalt Materials, Mixture Design and Construction”Maryland.”

Roman, C. 2017. Linear Rheology of Bituminous Mastics Modified with Various Polyolefinsa: Comparative Study with Their Source Binders.

Singh, V., and R. Sakale,. 2018. "The Effect of Using Waste Plastic and Waste Glass On the Asphalt Pavement Properties." International Journal of Research in Engineering and Technology 07(02).

Tadesse, Dinku, A. 2017. "Conceptual Cost Estimation of Road Projects in Ethiopia Using Neural Networks." 19–29.

Thomas Yager,. 2016. The Mineral Industry of Ethiopia, US Department of the Interior. US Geological Survey.

Transportation Research,. 2011. Board Committee A Manual for Design of Hot Mix Asphalt with Community. National Cooperative Highway Research Program. Washington,DC.

Vivian Silveira, and Santos B,. 2013. Influence of Mineral Filler on Volumetric Properties of Hot Mix Asphalt. São Paulo. Brazil: International Journal of Pavements Conference.

Walle, H. 2000. "Building Stone of Centeral and Southern Ethiopia." (Issue 436):175–82.

Yarhim, Tam. 2006. "A Review on the Viable Technology for Construction Waste Recycling." Journal of Resources, Conservation and Recycling 47(issue3):209–21.

Yongjie, and Yang S. 2004. "Preparation and Properties of Glass-Asphalt Concrete. Key Laboratory for Silicate Materials Science and Engineering of Ministry of Education."

Zainudin, M. Z. 2016. "Effect of Sugarcane Bagasse Ash as Filler in Hot Mix Asphalt." Mater. Sci. Forum.

Zemichael,. 2007. "Effect of Different Types of Filler Materials on Characteristics of Hot-Mix-Asphalt Concrete Asphalt Concrete."

Zemichael, Berehe Mehari. 2007. "Effect of Different Types of Filler Materials on Characteristics of Hot-Mix-Asphalt Concrete."

Zewde, S. 2011. "Marble Potential in Ethiopia, Addis Ababa."

Zulkati, Z. 2010. "Effects of Fillers on Properties of Asphalt -Concrete Mixture." Journal of Transportation Engineering no .7(ASCE,vol.138).

LIST OF APPENDIX

APPENDIX A: Physical properties of mineral filler test results

TEST METHOD: ASTM D-854

Table A 1. Physical Properties of Crushed Stone Dust Filler

Material Type :	Crushed Stone Dust		
Trial No	1.00	2.00	3.00
Mass of Pycnometer ,(g)	30.62	25.89	26.88
Mass of Pycnometer soil and Water,g (Wb)	141.73	136.42	138.02
Final Temperature in degree Celicuous,Tx where k=0.9991	25.00	25.00	25.00
Mass of Soil ,(g)) (Wo)	25.08	25.17	25.12
Mass of Pycnometer with Water at Final Temp,Tx (g) (Wa)	125.56	121.68	122.24
Apparent Specific Gravity ,Gs=(Wo/Wo+(Wa-Wb))*K	2.81	2.41	2.69
Average Apparent Specific Gravity	2.64		

Table A 2. Physical Properties of CR

Material Type :	CR		
Trial No	1.00	2.00	3.00
Mass of Pycnometer ,(g)	27.72	27.78	22.52
Mass of Pycnometer soil and Water,g (Wb)	139.40	139.80	133.20
Final Temperature in degree Celicuous,Tx (k=0.9991)	25.00	25.00	25.00
Mass of Soil ,(g)) (Wo)	19.66	21.00	20.00
Mass of Pycnometer with Water at Final Temp,Tx (g) (Wa)	128.12	129.04	119.43
Apparent Specific Gravity ,Gs=(Wo/Wo+(Wa-Wb))*K	2.34	2.05	3.21
Average Apparent Specific Gravity	2.53		

Table A 3. Physical Properties of WMD

Material Type :	WMD		
Trial No	1.00	2.00	3.00
Mass of Pycnometer ,(g)	26.88	22.52	27.22
Mass of Pycnometer soil and Water,g (Wb)	136.06	132.22	137.60
Final Temperature in degree Celicuous,Tx (k24= 0.9991)	25.00	25.00	25.00
Mass of Soil ,(g)) (Wo)	20.00	20.00	20.00
Mass of Pycnometer with Water at Final Temp,Tx (g) (Wa)	126.44	121.62	122.54
Apparent Specific Gravity ,Gs=(Wo/Wo+(Wa-Wb))*K	1.93	2.13	4.04
Average Apparent Specific Gravity	2.70		

APPENDIX B: Physical properties of aggregate test results

Table B-1 Specific Gravity and Absorption of Fine Aggregate TEST METHOD: AASHTO T 85-95

<table>
<tr><td colspan="5">Trial</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td>AVER</td></tr>
<tr><td colspan="5">B. Mass of Pycnometer+Weter</td><td colspan="2">1564.00</td><td colspan="2">1544.70</td><td colspan="2">1544.11</td><td></td></tr>
<tr><td colspan="5">S. Mass of SSD Sample in air</td><td colspan="2">509.31</td><td colspan="2">511.00</td><td colspan="2">508.60</td><td></td></tr>
<tr><td colspan="5">C. Mass of Pycnometer+Weter +Sample</td><td colspan="2">1869.62</td><td colspan="2">1869.90</td><td colspan="2">1869.34</td><td></td></tr>
<tr><td colspan="5">A. Mass of Oven dry sample in air</td><td colspan="2">501.60</td><td colspan="2">504.70</td><td colspan="2">503.69</td><td></td></tr>
<tr><td colspan="5">Water Temperature</td><td colspan="2">23</td><td colspan="2">22</td><td colspan="2"></td><td></td></tr>
<tr><td>oC</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>-</td><td>25</td><td>26</td><td>27</td><td>28
29</td></tr>
<tr><td>K</td><td>1.0004</td><td>1.0002</td><td>1</td><td>0.9998</td><td>0.9996</td><td>0.9993</td><td>0.999</td><td>0.9991</td><td>0.9986</td><td>0.999</td><td>0.998
0.9977</td></tr>
<tr><td colspan="5">Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)</td><td colspan="2">2.460</td><td colspan="2">2.713</td><td colspan="2">2.744</td><td>2.64</td></tr>
<tr><td colspan="5">Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)</td><td colspan="2">2.498</td><td colspan="2">2.746</td><td colspan="2">2.771</td><td>2.67</td></tr>
<tr><td colspan="5">Apparent specific gravity Sr = A*k/(A+B-C)</td><td colspan="2">2.557</td><td colspan="2">2.808</td><td colspan="2">2.820</td><td>2.73</td></tr>
<tr><td colspan="5">Water absorption (%) Aw = (S-A)*100/A</td><td colspan="2">1.537</td><td colspan="2">1.248</td><td colspan="2">0.975</td><td>1.25</td></tr>
</table>

Table B-2 Specific Gravity and Absorption of intermidet Coarse Aggregate test method: AASHTO T 85-91

<table>
<tr><td colspan="5">Trial</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td>AVER</td></tr>
<tr><td colspan="5">S. Mass of SSD sample in air (g)</td><td colspan="2">2000</td><td colspan="2">2000</td><td colspan="2">2000</td><td></td></tr>
<tr><td colspan="5">B. Mass of basket in water (g)</td><td colspan="2">626.71</td><td colspan="2">682.40</td><td colspan="2">641.54</td><td></td></tr>
<tr><td colspan="5">C Bs+C Basket + Sample in water (g)</td><td colspan="2">1863.76</td><td colspan="2">1911.00</td><td colspan="2">1876.65</td><td></td></tr>
<tr><td colspan="5">.Mass of saturated sample in water (g)</td><td colspan="2">1986.60</td><td colspan="2">2003.50</td><td colspan="2">2006.5</td><td></td></tr>
<tr><td colspan="5">A. Mass of oven dry sample in air</td><td colspan="2">1976.70</td><td colspan="2">1983.80</td><td colspan="2">1977.42</td><td></td></tr>
<tr><td>oC</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>-</td><td>25</td><td>26</td><td>27</td><td>28
29</td></tr>
<tr><td>K</td><td>1.0004</td><td>1.0002</td><td>1</td><td>0.9998</td><td>0.9996</td><td>0.9993</td><td>0.999</td><td>0.9991</td><td>0.9986</td><td>0.999</td><td>0.998
0.9977</td></tr>
<tr><td colspan="5">Bulk sp. gravity (oven dry) Sd = A*k/S-(C-B)</td><td colspan="2">2.589</td><td colspan="2">2.568</td><td colspan="2">2.583</td><td>2.580</td></tr>
<tr><td colspan="5">Bulk sp. gravity (SSD) Ss = S*k/S-(C-B)</td><td colspan="2">2.619</td><td colspan="2">2.589</td><td colspan="2">2.612</td><td>2.607</td></tr>
<tr><td colspan="5">Apparent specific gravity Sr = A*k/A-(C-B)</td><td colspan="2">2.670</td><td colspan="2">2.623</td><td colspan="2">2.661</td><td>2.652</td></tr>
<tr><td colspan="5">Water absorption Aw = (S-A)*100/A</td><td colspan="2">1.179</td><td colspan="2">0.817</td><td colspan="2">1.142</td><td>1.046</td></tr>
</table>

Table B-3 Specific Gravity and Absorption of Coarse Aggregate TEST METHOD: AASHTO T 85-91

<table>
<tr><td colspan="5">Trial</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td>AVER</td></tr>
<tr><td colspan="5">S. Mass of SSD sample in air (g)</td><td colspan="2">2000</td><td colspan="2">2000</td><td colspan="2">2000</td><td></td></tr>
<tr><td colspan="5">B. Mass of basket in water (g)</td><td colspan="2">681.41</td><td colspan="2">678.72</td><td colspan="2">699.5</td><td></td></tr>
<tr><td colspan="5">C Bs+C Basket + Sample in water (g)</td><td colspan="2">1929.10</td><td colspan="2">1916.76</td><td colspan="2">1938.8</td><td></td></tr>
<tr><td colspan="5">.Mass of saturated sample in water (g)</td><td colspan="2">2021.50</td><td colspan="2">2013.00</td><td colspan="2">2022</td><td></td></tr>
<tr><td colspan="5">A. Mass of oven dry sample in air</td><td colspan="2">1996.40</td><td colspan="2">1989.02</td><td colspan="2">1996.43</td><td></td></tr>
<tr><td>ºC</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>-</td><td>25</td><td>26</td><td>27</td><td>28
29</td></tr>
<tr><td>K</td><td>1.0004</td><td>1.0002</td><td>1</td><td>0.9998</td><td>0.9996</td><td>0.9993</td><td>0.999</td><td>0.9991</td><td>0.9986</td><td>0.999</td><td>0.998
0.9977</td></tr>
<tr><td colspan="5">Bulk sp. gravity (oven dry) Sd = A*k/S-(C-B)</td><td colspan="2">2.651</td><td colspan="2">2.607</td><td colspan="2">2.622</td><td>2.627</td></tr>
<tr><td colspan="5">Bulk sp. gravity (SSD) Ss = S*k/S-(C-B)</td><td colspan="2">2.656</td><td colspan="2">2.621</td><td colspan="2">2.627</td><td>2.635</td></tr>
<tr><td colspan="5">Apparent specific gravit Sr = A*k/A-(C-B)</td><td colspan="2">2.664</td><td colspan="2">2.645</td><td colspan="2">2.634</td><td>2.648</td></tr>
<tr><td colspan="5">Water absorption Aw = (S-A)*100/A</td><td colspan="2">0.180</td><td colspan="2">0.552</td><td colspan="2">0.179</td><td>0.304</td></tr>
</table>

Table B-4 Aggregate Crushing Value TEST METHOD: BS: 812 Part 110 (1990)

TRIAL No.	1	2	3
Mass of mold and plate (gm)	11920.5	11920.5	11920.5
Mass of sample (14mm pass and 10mm Retain)(M1)	2623.36	2622.29	2676.28
Mass of sample passing B.S Sieve,2.36mm (gm) (M2)	470.5	451.4	482.7
Aggregate Crushing Value (ACV) (%)=(M2/M1)*100	17.94	17.21	18.04
Average ACV (%)	17.73		

Table B-5 Aggregate impact value

TRIAL No.	1	2
mold (g)	2749.5	2749.5
mold + sample	3433.7	3486.6
sample (M1)	687.52	739.11
weight of aggregate passing on seive 2.34mm(gm) (M2)	56.27	62.21
Aggregate impact value (%)=(M2/M1)*100	8.18	8.42
Average impact value(%)	8.30	

Table B-6 Los Angeles abrasion

TRIAL No.	1	2
NUMBER OF REVOLUTION	500	500
TOTAL WT. OF SAMPLE TESTED, (g)	5000	5000
WT. OF TESTED SAMPLE RETAINED No. 12 SIEVE (g)	4489.36	4466
PERCENT LOSS (%)	10.2128	10.68
Average los angeles abrasion (%)	10.45	

Table B-7 Flakiness Index Record

Separated fraction Size, mm	Mass		individual fraction % of M1(g)	Sum of masses after discarding 5% or less. M2(g)	mass of flaky passing(g)	Sum, M3(g)
	individual fraction(g)	Sum, M1 (g)				
28 to 20	832	4989.5	16.68	4989.5	266	1843
20 to 14	1133		22.71		367.5	
14 to 10	812		16.27		319	
10 to 6.3	2212.5		44.34		890.5	
FLAKINESS INDEX (%)=(M3/M2)*100						36.94

Table B-8 Specific Gravity and Absorption Test specific gravity of semi-solid bituminous materials (T228)

Source:	Asphalt Batching Plant	
Tirial	1	2
1. Weight of Pycnometer , g	104.55	103.33
2. Weight of Pycnometer Filled With Sample,g	167.34	166.88
3. Weight of Pycnometer Filled with Water , g @ 25 ± 0.10C	244.55	249.42
4. Weight of Pycnometer + Sample + Water , g @ 25± 0.10C	248.79	250.22
5. Weight of Water replaced by Sample , g {(3-1)+2} – 4	58.55	62.75
6. Specific Gravity ,(2-1)/5	1.072	1.013
7. Average Specific Gravity (g/ Cm3)	1.043	
8. Density , 7*wT (25 oC,wT =0.9971 g/cm3)	1.040	
9. Density , 7*wT (15.6 oC, wT =0.9990 g/cm3)	1.042	

APPENDIX C: Bitumen quality tests

Table C-1 Test Records of Penetration, Ductility, Softening point, flash point and Specific Gravity of Bituminous Materials

Penetration	Test Method	Test No	Test Temp(degree celcious	Time of Test (S)	Test Load (g)	Reading Date (0.1mm)			Average(0.1mm
						1st Time	2nd time	3rd time	
	AASHTO T 49	1	25^0C	5	100	58.74	59.98	60.87	59.86
		2	25^0C	5	100	68.81	69.62	69.81	69.41
		3	25^0C	5	100	61.93	62.78	63.67	62.79
AASHTO T 49									64.02

Softening point	Test Method	Test no	Temp.when starting heating (degree celcious)	Record of liquid Temp in beaker			Softening point
				4min	5min	6min	
	AASHTO T 53	1	7	4min			51.2
		2	7	4min			51.6
	Average						51.4

Ductility	Test Method	Test No	Test Temp(degree celcious	Speed (cm/min)	Ductility (cm)	Average (cm)
	AASHTO T 51	1	25^0C	5	92	93.7
		2	25^0C	5	94	
		3	25^0C	5	95	

Flash Point	Test Method	Flash Point
	AASHTO T 48	290^0C

APPENDIX D: Test results of marshall mix design

Table D-1: Marshall Test Results Prepared by 4.5% Crushed Stone Dust Filler Content by Weight of Total Mix MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Specimen t No	Bitumen content %	Height of specimen (cm)	Weight of specimen t in air (gm)	Wt of spacimen t in water (gm)	Wt of spacimen t in SDD (gm)	Bulk volume (cc)	Bulk SG comp mix(Gmb) (cc)	max spacific gravity (Gmm)	Air void	VMA %]	VFA %	Marshal stability KN			Flow (mm)
						E-D	C/F		(H-G) *100/H	(100-[(Gsb*Pa/ Gsb)	100*(J-I)/J	Load	Coff factor	Corrected load N*M*ring factor	
1	4%	6.9	1218.0	703.0	1224.0	521.0	2.33781					10.34	0.92843	9.60	2.66
2		6.8	1217.0	701.5	1220.5	519.0	2.34489					10.20	0.88627	9.04	3.89
3		7.0	1219.0	700.0	1221.0	521.0	2.33973					10.29	0.862	8.87	2.24
Average		6.9	1218.0	701.5	1221.8	520.3	2.34081	2.471	5.3	13.6	61.3	10.28	0.89231	9.17	2.93
1	4.50%	6.8	1220.0	703.5	1222.0	518.5	2.35294					14.62	0.70178	10.26	3.32
2		7.0	1216.0	702.5	1218.0	515.5	2.35887					12.11	0.89843	10.88	2.78
3		7.0	1220.0	703.0	1221.0	518.0	2.35521					13.70	0.84745	11.61	3.66
Average		6.9	1218.7	703.0	1220.3	517.3	2.35567	2.442	3.5	13.5	73.8	13.48	0.81004	10.92	3.25
1	5%	6.9	1227.0	706.0	1228.5	522.5	2.34833					14.57	0.80096	11.67	3.32
2		6.8	1226.0	706.5	1227.5	521.0	2.35317					13.47	0.9369	12.62	2.87
3		6.9	1225.0	707.5	1226.0	518.5	2.36258					14.04	0.82977	11.65	3.67
Average		6.9	1226.0	706.7	1227.3	520.7	2.35467	2.431	3.1	14.0	77.6	14.03	0.85409	11.98	3.29
1	5.50%	6.8	1222.0	704.0	1222.5	518.5	2.3568					12.62	0.94057	11.87	3.76
2		6.8	1221.0	706.0	1226.0	520.0	2.34808					14.62	0.72093	10.54	3.24
3		6.8	1226.0	707.0	1227.5	520.5	2.35543					14.00	0.72857	10.20	3.35
Average		6.8	1223.0	705.7	1225.3	519.7	2.35343	2.405	2.1	14.5	85.2	13.75	0.79074	10.87	3.45
1	6%	6.9	1228.0	702.0	1221.0	519.0	2.36609					10.59	0.92162	9.76	3.56
2		6.8	1221.0	700.0	1222.0	522.0	2.33908					11.00	0.96727	10.64	3.76
3		6.7	1221.0	701.0	1222.5	521.5	2.34132					10.64	0.86842	9.24	3.77
Average		6.8	1223.3	701.0	1221.8	520.8	2.3488	2.397	2.0	15.1	86.7	10.74	0.91964	9.88	3.70

Table D-2 : Marshall Test Results Prepared by 5.5 % Crushed Stone Dust Filler Content by Weight of Total Mix MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Specimen t No	Bitumen content %	Height of specimen (cm)	Weight of specimen t in air (gm)	Wt of spacimen t in water (gm)	Wt of spacimen t in SDD (gm)	Bulk volume (cc)	Bulk SG comp mix(Gmb) (cc)	max spacific gravity (Gmm)	Air void	VMA %]	VFA %	Marshal stability KN			Flow (mm)
						E-D	C/F		(H-G) *100/H	(100-[(Gsb*Pa/ Gsb)	100*(J-I)/J	Load	Coff factor	Corrected load N*M*ring factor	
1	4%	6.9	1216.0	700.5	1222.0	521.5	2.33174					10.34	1.02515	10.60	2.68
2		6.8	1215.0	698.5	1218.5	520.0	2.33654					10.20	0.9451	9.64	2.95
3		7.0	1216.0	697.5	1218.0	520.5	2.33622					10.29	0.95918	9.87	2.98
Average		6.9	1215.7	698.8	1219.5	520.7	2.33483	2.471	5.5	13.8	60.1	10.28	0.97665	10.04	2.87
1	4.50%	6.8	1223.0	701.5	1225.0	523.5	2.3362					14.62	0.83174	12.16	3.10
2		7.0	1219.0	701.0	1221.0	520.0	2.34423					12.11	0.84889	10.28	2.90
3		7.0	1221.0	701.5	1222.0	520.5	2.34582					13.70	0.84745	11.61	3.23
Average		6.9	1221.0	701.3	1222.7	521.3	2.34207	2.442	4.1	14.0	70.8	13.48	0.8422	11.35	3.08
1	5%	6.9	1229.0	705.5	1230.5	525.0	2.34095					14.57	0.79616	11.60	3.39
2		6.8	1225.0	706.0	1226.5	520.5	2.35351					13.47	1.01114	13.62	2.93
3		6.9	1228.0	707.0	1229.0	522.0	2.35249					14.04	0.87963	12.35	3.50
Average		6.9	1227.3	706.2	1228.7	522.5	2.34896	2.431	3.4	14.2	76.2	14.03	0.89282	12.52	3.27
1	5.50%	6.8	1226.0	704.5	1226.0	521.5	2.35091					12.62	0.91125	11.50	3.24
2		6.8	1223.0	705.5	1227.0	521.5	2.34516					14.62	0.73871	10.80	3.51
3		6.8	1223.0	706.0	1225.5	519.5	2.35419					14.00	0.83571	11.70	3.54
Average		6.8	1224.0	705.3	1226.2	520.8	2.35008	2.405	2.3	14.6	84.4	13.75	0.82444	11.33	3.43
1	6%	6.9	1226.0	701.5	1219.0	517.5	2.36908					10.59	0.94145	9.97	3.62
2		6.8	1223.0	699.0	1223.0	524.0	2.33397					11.00	0.91545	10.07	3.80
3		6.7	1224.0	700.5	1220.5	520.0	2.35385					10.64	0.89662	9.54	3.61
Average		6.8	1224.3	700.3	1220.8	520.5	2.35223	2.397	1.9	15.0	87.5	10.74	0.91778	9.86	3.68

Table D-3: Marshall Test Results Prepared by 6.5 % Crushed Stone Dust Filler Content by Weight of Total Mix MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559/AASHTO T 245

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Specimen t No	Bitumen content %	Height of specimen (cm)	Weight of specimen t in air (gm)	Wt of spacimen t in water (gm)	Wt of spacimen t in SDD (gm)	Bulk volume (cc)	Bulk SG comp mix(Gmb) (cc)	max spacific gravity (Gmm)	Air void	VMA %]	VFA %	Marshal stability KN			Flow (mm)
									(H-G) *100/H	(100-[(Gsb*Pa/Gsb)	100*(J-I)/J	Load	Coff factor	Corrected load	
						E-D	C/F							N*M*ring factor	
1	4%	6.9	1223.0	699.0	1229.0	530.0	2.30755					10.34	0.83172	8.60	2.78
2		6.8	1232.0	698.5	1225.0	526.5	2.33998					10.20	0.96765	9.87	2.98
3		7.0	1234.0	699.5	1235.0	535.5	2.30439					10.29	0.97085	9.99	3.06
Average		6.9	1229.7	699.0	1229.7	530.7	2.31721	2.471	6.2	14.5	57.1	10.28	0.92313	9.49	2.94
1	4.50%	6.8	1223.0	701.0	1225.0	524.0	2.33397					14.62	0.77428	11.32	3.30
2		7.0	1224.0	699.5	1225.5	526.0	2.327					12.11	0.8621	10.44	2.75
3		7.0	1227.0	700.5	1228.5	528.0	2.32386					13.70	0.77007	10.55	3.73
Average		6.9	1224.7	700.3	1226.3	526.0	2.32826	2.442	4.7	14.5	67.9	13.48	0.79916	10.77	3.26
1	5%	6.9	1235.0	705.5	1236.0	530.5	2.32799					14.57	0.78449	11.43	3.55
2		6.8	1232.0	706.0	1233.5	527.5	2.33555					13.47	0.85004	11.45	2.93
3		6.9	1234.0	708.5	1236.0	527.5	2.33934					14.04	0.89316	12.54	3.80
Average		6.9	1233.7	706.7	1235.2	528.5	2.33428	2.431	4.0	14.7	72.9	14.03	0.84173	11.81	3.43
1	5.50%	6.8	1233.0	706.0	1234.5	528.5	2.33302					12.62	0.88986	11.23	3.66
2		6.8	1229.0	707.5	1230.5	523.0	2.3499					14.62	0.69152	10.11	3.35
3		6.8	1230.0	709.0	1231.5	522.5	2.35407					14.00	0.76429	10.70	3.77
Average		6.8	1230.7	707.5	1232.2	524.7	2.34562	2.405	2.5	14.7	83.2	13.75	0.77692	10.68	3.59
1	6%	6.9	1223.0	710.5	1225.0	514.5	2.37707					10.59	0.91313	9.67	3.45
2		6.8	1228.0	706.5	1230.0	523.5	2.34575					11.00	0.89727	9.87	3.78
3		6.7	1231.0	707.5	1233.0	525.5	2.34253					10.64	0.92857	9.88	3.88
Average		6.8	1227.3	708.2	1229.3	521.2	2.35497	2.397	1.8	14.9	88.2	10.74	0.91281	9.81	3.70

APPENDIX E: Replacement of WMD and CR

Table E-1: Marshall Test Results Prepared by WMD Filler Content by Weight of Total Mix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Specimen t No	WMD content %	Height of specimen (mm)	Weight of specimen t in air (gm)	Wt of spacimen t in water (gm)	Wt of spacimen t in SDD (gm)	Bulk volume (cc)	Bulk SG comp mix (Gmb) (cc)	max spacific gravity (Gmm)	Air void %	VMA %]	VFA %	Marshal stability KN			Flow (mm)
						E-D	C/F		(H-G) *100/H	(100-[(Gsb*Pa /Gsb)	100*(J-I)/J	Load	Coff factor	Corrected load N*M*ring factor	
1	0.00%	6.53	1246.0	710.0	1247.5	537.5	2.318					15.86	0.79887	12.67	2.08
2		6.63	1247.5	711.0	1249.0	538.0	2.319					15.50	0.82968	12.86	3.23
3		6.61	1249.0	714.0	1250.5	536.5	2.328					15.78	0.87326	13.78	3.12
Average		6.59	1247.5	711.7	1249.0	537.3	2.322	2.440	4.85	14.50	66.55	15.71	0.83369	13.10	2.81
1	20.00%	6.52	1234.0	703.0	1235.5	532.5	2.317					12.34	0.84279	10.40	3.12
2		6.63	1235.0	704.0	1237.0	533.0	2.317					11.23	0.90027	10.11	3.32
3		6.63	1236.5	706.0	1238.0	532.0	2.324					11.87	0.95535	11.34	11.34
		6.59	1235.2	704.3	1236.8	532.5	2.320	2.424	4.31	14.60	70.49	12.10	0.87741	10.62	3.28
1	40.00%	6.43	1248.0	715.5	1250.0	534.5	2.335					15.19	0.68664	10.43	3.08
2		6.60	1249.0	716.0	1250.5	534.5	2.337					12.05	0.93942	11.32	2.87
3		6.70	1251.0	718.0	1253.0	535.0	2.338					13.42	0.88376	11.86	3.05
Average		6.58	1249.3	716.5	1251.2	534.7	2.337	2.440	4.24	13.90	69.53	13.32	0.84109	11.20	3.00
1	60.00%	6.63	1252.0	719.0	1254.0	535.0	2.340					14.21	0.81210	11.54	2.82
2		6.53	1251.0	724.0	1253.0	529.0	2.365					14.98	0.79239	11.87	3.54
3		6.53	1249.0	722.0	1251.0	529.0	2.361					15.05	0.80532	12.12	3.02
Average		6.56	1250.7	721.7	1252.7	531.0	2.355	2.456	4.10	13.20	68.94	14.88	0.79592	11.84	3.13
1	80.00%	6.63	1259.0	724.0	1260.5	536.5	2.347					13.34	0.88906	11.86	3.06
2		6.60	1258.5	728.5	1260.0	531.5	2.368					15.33	0.77234	11.84	2.54
3		6.50	1260.0	726.5	1261.0	534.5	2.357					14.90	0.85101	12.68	3.22
Average		6.58	1259.2	726.3	1260.5	534.2	2.357	2.443	3.51	13.20	73.41	15.01	0.80791	12.13	2.94
1	100.00%	6.60	1252.0	716.0	1253.5	537.5	2.329					11.20	1.14107	12.78	2.42
2		6.63	1254.0	717.0	1255.5	538.5	2.329					12.34	1.05186	12.98	3.07
3		6.60	1254.5	716.5	1260.0	543.5	2.308					11.69	1.17707	13.76	3.31
Average		6.61	1253.5	716.5	1256.3	539.8	2.322	2.411	3.69	14.50	74.55	11.45	1.15051	13.17	2.93

Table E-2: Marshall Test Results Prepared by CR Filler Content by Weight of Total Mix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Specimen t No	CR content %	Height of specimen (mm)	Weight of specimen t in air (gm)	Wt of spacimen t in water (gm)	Wt of spacimen t in SDD (gm)	Bulk volume (cc)	Bulk SG comp mix (Gmb) (cc)	max spacific gravity (Gmm)	Air void %	VMA %]	VFA %	Marshal stability KN			Flow (mm)
						E-D	C/F		(H-G) *100/H	(100-[(Gsb*Pa /Gsb)	100*(J-I)/J	Load	Coff factor	Corrected load N*M*ring factor	
1	0.00%	6.53	1246.0	710.0	1247.5	537.5	2.318					15.86	0.79887	12.67	2.08
2		6.63	1247.5	711.0	1249.0	538.0	2.319					15.50	0.82968	12.86	3.23
3		6.61	1249.0	714.0	1250.5	536.5	2.328					15.78	0.87326	13.78	3.12
Average		6.59	1247.5	711.7	1249.0	537.3	2.322	2.440	4.85	14.50	66.55	15.71	0.83369	13.10	2.81
1	5.00%	6.52	1253.0	716.0	1254.0	538.0	2.329					12.34	0.91653	11.31	3.10
2		6.63	1249.5	713.0	1251.0	538.0	2.322					11.23	1.03651	11.64	3.44
3		6.63	1251.0	715.0	1252.5	537.5	2.327					11.87	1.06824	12.68	12.68
		6.59	1251.2	714.7	1252.5	537.8	2.326	2.424	4.03	14.30	71.82	12.10	0.98154	11.88	3.25
1	15.00%	6.43	1249.0	715.5	1250.5	535.0	2.335					15.19	0.79789	12.12	3.11
2		6.60	1250.5	716.0	1251.5	535.5	2.335					12.05	0.98672	11.89	2.09
3		6.70	1242.0	717.5	1243.0	525.5	2.363					13.42	0.94411	12.67	3.22
Average		6.58	1247.2	716.3	1248.3	532.0	2.344	2.440	3.92	13.70	71.37	13.32	0.91792	12.23	2.81
1	25.00%	6.63	1244.5	718.0	1246.0	528.0	2.357					14.21	0.88388	12.56	2.65
2		6.53	1244.0	720.0	1245.0	525.0	2.370					14.98	0.84713	12.69	2.73
3		6.53	1242.0	719.0	1243.0	524.0	2.370					15.05	0.89169	13.42	2.98
Average		6.56	1243.5	719.0	1244.7	525.7	2.366	2.456	3.68	12.80	71.23	14.88	0.86626	12.89	2.79
1	35.00%	6.63	1249.5	721.0	1251.0	530.0	2.358					13.34	0.88156	11.76	2.97
2		6.60	1252.0	723.5	1253.0	529.5	2.364					15.33	0.70320	10.78	3.23
3		6.50	1252.5	721.0	1254.0	533.0	2.350					14.90	0.70000	10.43	3.06
Average		6.58	1251.3	721.8	1252.7	530.8	2.357	2.443	3.51	13.20	73.42	15.01	0.73218	10.99	3.09
1	45.00%	6.60	1246.0	708.0	1247.0	539.0	2.312					11.20	0.86339	9.67	3.60
2		6.63	1248.5	709.0	1250.0	541.0	2.308					12.34	0.86305	10.65	3.54
3		6.60	1243.0	706.5	1244.0	537.5	2.313					11.69	0.84089	9.83	3.81
Average		6.61	1245.8	707.8	1247.0	539.2	2.311	2.411	4.16	14.90	72.07	11.45	0.87773	10.05	3.65

APPENDIX F: Moisture susceptibility test result

Resistance of compacted bituminious mixture to moisture damage	
layer asphalt wearing course	Source of bitumen **ERA**
Compaction 75 blow per side	Grade of bitumen **60/70**
Specific gravity of Bitumen 1.012 Mix type 19mm NMAS	

Trial	CSD	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	100%	7.99	7990	9.12	9120	3.14	68.66	69.66	100	741.2135	833.8957	0.888856	**85.61%**
2		7.67	7670	9.43	9430	3.14	69	70.33	100	708.0218	854.0266	0.829039	
3		7.88	7880	9.22	9220	3.14	69	68.66	100	727.407	855.3177	0.850452	
										Mean		0.856116	

Trial	WMD	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	100	7.77	7770	8.78	8780	3.14	66.33	67	100	746.1246	834.6801	0.893905	**86.49%**
2		7.63	7630	8.89	8890	3.14	67	68.66	100	725.3541	824.7044	0.879532	
3		7.44	7440	9.06	9060	3.14	68	68	100	696.8902	848.6324	0.821192	
										Mean		0.864876	

Trial	WMD	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	80%	6.98	6980	8.03	8030	3.14	65	66	100	683.9784	774.9469	0.882613	**84.37%**
2		7.33	7330	9.08	9080	3.14	67	67.66	100	696.8343	854.7797	0.815221	
3		7.75	7750	9.44	9440	3.14	66	67	100	747.9251	897.4237	0.833414	
										Mean		0.843749	

Trial	WMD	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	60%	6.72	7720	8.96	8960	3.14	66.33	67	100	741.3233	851.792	0.87031	**82.77%**
2		7.07	7070	8.86	8860	3.14	66	67	100	682.3007	842.2854	0.810059	
3		7.25	7250	9.12	9120	3.14	68	68.66	100	679.0933	846.041	0.802672	
										Mean		0.82768	

Resistance of compacted bituminious mixture to moisture damage	
layer asphalt wearing course	Source of bitumen **ERA**
Compaction 75 blow per side	Grade of bitumen **60/70**
Specific gravity of Bitumen 1.012 Mix type 19mm NMAS	

Trial	CSD	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	100%	7.99	7990	9.12	9120	3.14	68.66	69.66	100	741.2135	833.8957	0.888856	**85.61%**
2		7.67	7670	9.43	9430	3.14	69	70.33	100	708.0218	854.0266	0.829039	
3		7.88	7880	9.22	9220	3.14	69	68.66	100	727.407	855.3177	0.850452	
										Mean		0.856116	

Trial	CR	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	10	7.61	7610	9.14	9140	3.14	67	66	100	723.4528	882.0691	0.820177	**82.25%**
2		7.32	7320	9.12	9120	3.14	67	68.66	100	695.8836	846.041	0.822518	
3		7.76	7760	9.55	9550	3.14	67	68	100	737.7127	894.5298	0.824693	
										Mean		0.822463	

Trial	CR	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	15%	7.22	7220	8.94	8940	3.14	66	67	100	696.7767	849.8907	0.819843	**84.12%**
2		7.96	7960	9.13	9130	3.14	68	67.66	100	745.5976	859.4866	0.867492	
3		7.68	7680	9.43	9430	3.14	66.22	68	100	738.7073	883.2896	0.836314	
										Mean		0.841216	

Trial	CR	WetP(KN)	WetP(N)	Dry P(KN)	Dry P(N)	PI (Π)	Thickness wet (mm)	Thickness dry (mm)	Diameter (mm)	St_2	St_1	TSR	Average TSR (%)
1	20%	6.98	6980	8.43	8430	3.14	66.33	67	100	670.2638	801.407	0.836359	**82.61%**
2		7.11	7110	8.54	8540	3.14	67	66.33	100	675.9198	820.0649	0.824227	
3		7.25	7250	8.78	8780	3.14	68.66	68	100	672.5655	822.4054	0.817803	
										Mean		0.82613	

		Doc.Number: GLD/F5.10.2	Version No: 1
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	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -08/09/2021

Customer Name:- Haile Zenebe

Request No:- GLD/RQ/10/21

Report No:- GLD/RN/815/21

Sample type :Quartiz

Sample Preparation: - 200 Mesh

Date Submitted:-14/07/2021

Number of Sample:-Two (02)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	SO_3	TiO_2	H_2O	LOI
Waste Marble Dust	52.44	7.15	12.51	17.51	2.07	0.61	4.23	<0.01	1.92	0.01	0.90	0.62
Crumb Rubber Dust	47.33	9.96	11.78	14.44	2.33	1.43	4.07	<0.01	2.66	0.01	0.92	4.34

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
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Tizita Zemene

Approved By
Yohannes Getachew

Quality Control
Gosa Haile

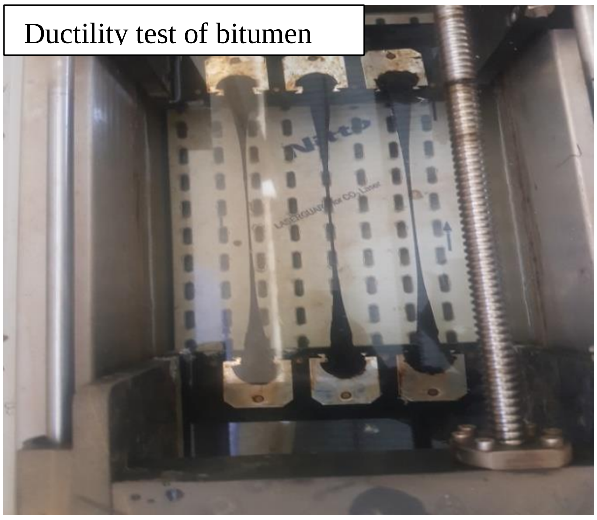
APPENDIX G: Photograph during laboratory work

Sample preparing of AIV

Aggregate crushing value machine

Prepared ductility specimen

Ductility test of bitumen



Prepared flash and fire specimen

Flash and fire point test

Socked specific gravity sample of filler

Mixing GMM

Marshal compaction

measuring specimen

Compacted Specimen in Water bath

Adjusting Marshall Test machine

120 Specimen OBC,OFC, replacement & TSR